Section 3: Existing Vegetation Mapping Protocol

3.1 Purpose

The purpose of this protocol is to define specific data standards and provide guidelines for mapping methodology associated with four map levels. The four levels are intended to meet a full range of business requirements from national to sub-forest geographic extents.

3.11 Background and Specific Objectives

Consistent map products currently exist in widely scattered locations across the agency and were developed in the absence of national standards. The objective of this technical guide is to provide direction for the development of consistent and continuous existing vegetation map products at the four hierarchical levels. Successful implementation of these standards and guidelines will allow appending of existing vegetation maps at the appropriate level and facilitate consistent and comparable analysis within and across Forests, Regions, and the nation. Additionally, consistent vegetation maps at ecologically based extents (*e.g.*, ecological sections) are important to serve the forest, multi-forest, regional, and national business requirements.

This protocol identifies data standards and provides guidelines for map project planning, design, development and assessment; field and aerial photography data; and metadata/documentation. It is not the intent of this protocol to be directly prescriptive with respect to methods for project planning and product development; however, numerous specific methodological considerations are provided as references for the planning and implementation of the mapping process. It is the role of program and project managers to determine the most cost-effective and appropriate means for meeting existing vegetation information needs. A bulleted synopsis summarizing content is included at the beginning of each primary subsection.

These guidelines are organized as follows:

Project Management
- Information Needs Assessment Process
- Identify Resources Needed for Mapping
- Vegetation Mapping Project Plan, Schedule, and Budget

Map Standards
- Map Unit Keys
- Map Attributes
- Thematic Accuracy
- Minimum Map Feature
- Georegistration
- Update Schedule
- Metadata

Map Design
- Map Unit Design
- Map Feature Design

- Map Design Example

Map Product Development and Assessment

- Vegetation Mapping Overview
- Producing a Mid-Level Existing Vegetation Map
- Producing a Base-Level Map
- Principles of Map Product Development and Assessment
  - Existing Information Sources
    - Map Feature Delineation
    - Map Feature Attribution
    - Reference Data
    - Thematic Map Accuracy Assessment

Field Data Collection Standards and Methods
Field Data Forms
Aerial Photo Data Collection Standards and Methods
Aerial Photo Data Forms
Field Reviews
Metadata Entry Methods and Verification

- Metadata Required for Existing Vegetation Maps
- Specific Metadata Requirements in the FGDC Vegetation Classification Standard
- Metadata in Plain Language

Overview of Database Structure
Data Management

- Maintaining Existing Vegetation Maps

3.12 Business Requirements

In this section:

- ***The relationship of significant business functions to map levels***

Business requirements are the basis for identifying the basic data elements of the map unit design process. These business requirements are determined through an information needs assessment. Localized Forest Service and cooperators' business requirements may be factored into the definition of standard data elements as well as additional data elements in existing vegetation map products.

Table 3.1 identifies a number of business functions common across the Forest Service. The standard map units and map features identified in this section of the technical guide are common to these business functions. In addition to the standard map units defined in this guide, specific business functions can drive the definition of regional or local standards. Additional local standards may include greater thematic detail, additional data elements, or finer spatial resolution. As part of a mapping project plan, consideration should be given to the map level most likely to provide the required information. Mapping additional elements will require additional resources.

In table 3.1 a number of agency business requirements are related to the map level(s) typically required supporting those functions. Many of those functions occur at several organizational levels of the agency and are often supported by different map products. The map product levels defined in section 1.32 are intended to support the basic information needs that exist throughout the Forest Service as well as define a relationship between the map products that support those needs.

Table 3.1. Existing Vegetation Map Levels Supporting Forest Service Business

Map Level	Representative Business Requirements
National	National Strategic Inventory
All levels	Land Management Planning
All levels	Cooperative Program Support
All levels	Post-Fire Assessment
Broad and Mid	Multi-Forest/Bioregional Planning
Broad, Mid, Base	Forest Risk Assessment
Broad, Mid, Base	Rangeland Assessment
Broad, Mid, Base	Cumulative Effects Analysis
Broad, Mid, Base	Viability Assessment
Mid and Base	Forest Plan Monitoring
Mid and Base	Forest/Regional Fuels Assessment
Mid and Base	Ecosystem Assessment by Watershed
Base	Project Planning, Monitoring, and Evaluation

3.13 Products

In this section:

- ***Map product format and content***
- ***Desirable by-products of mapping***

The primary product at each level of mapping will be a geospatial database and Federal Geographic Data Committee (FGDC) compliant metadata. The base-level map product will be a vector format geospatial database and the three remaining levels in the map hierarchy are optionally raster or vector format. These map products must meet the specified standards, be geographically continuous within the area of interest, and contain the data attributes identified in tables 3.3 through 3.7.

Data sources and deliverable by-products of a mapping process may include the following: remotely sensed data, including satellite imagery and aerial photography, Digital Elevation Models (DEMs), interim map products (image classifications, delineated polygons, *etc.*), and field reference data.

3.2 Planning, Design, Development, and Assessment

This section relates to project planning and map unit design outlined in section 3.11. Map standards will subsequently be defined for the spatial and thematic data attributes of the four levels of vegetation maps. Individual concepts of map unit design are detailed in the subsections below.

3.21 Project Management

> ***In this section:***
> - ***Steps for planning a mapping project***

Project management is the planning, organizing, and managing of resources (personnel, equipment, time, money, and data) to accomplish a defined objective.

Successful project management requires a clear definition of project objectives, identification of all tasks needed to reach the objectives, proper allocation of resources to accomplish tasks, and constant monitoring of task accomplishments and resource expenditures.

3.211 Information Needs Assessment Process

An information needs assessment begins by gathering general information about the requirements of planned natural resource project(s) and relating these needs to specific business requirements for a vegetation map. Information gathering activities may include the following:

- Identifying the Project Needs
  - Specify the project area (*e.g.*, watershed, forest, ecosection).
  - Specify the objectives of the project (*e.g*., analysis objectives and interpretation needs)
  - Include both the overall project goals and the expected individual products/activities in the list of objectives.
  - Consider the objectives within the context of time, budget, and staff constraints.

- Identifying the Data Requirements
  - Conduct preliminary research to locate and examine applicable existing vegetation data and other ancillary data.
  - Evaluate existing information for factors such as: currency, minimum standards compliance, attributes needed to meet project requirements, and correspondence to the area of interest.
  - Determine the need for developing and/or acquiring new datasets. This may include digitizing, purchasing imagery, and such.
  - Consider issues of scale, resolution, precision, and accuracy of the required data.
  - Identify the level and types of vegetation classification to be mapped based on analysis objectives and interpretation needs.

- Identifying Analytical Needs
  - Determine the analytical methods to satisfying the project objectives.

Determine the types of programs, models, or algorithms required for processing and analysis.

3.212 Identify Resources Needed for Mapping

If the results of the information needs assessment identify the need for human and information processing resources, then an acquisition plan should be developed. The following items are identified for in-house mapping. These same factors can be used to develop a government estimate of costs for outsource contracting for a vegetation map.

- Identifying the Processing System Requirements
    - Consider whether existing hardware and software are appropriate and adequate for performing project tasks and producing output products.
    - Determine whether the datasets are in the proper format.
    - Determine the types of preprocessing, processing, and post-processing operations that must be performed.
    - Consider whether the available data storage is adequate for processing and archiving.

- Identifying the Staffing Needs for the Project
    - Determine the availability of appropriate staff.
    - Determine the need to obtain outside expertise (*e.g.,* programmers, remote sensing specialists, resource specialists, statisticians, *etc.*).
    - Calculate the time needed to locate outside expertise in the context of project budget and schedule.
    - Consider training needs of project staff.

3.213 Vegetation Mapping Project Plan, Schedule, and Budget

The vegetation mapping project plan should be maintained and updated as a written document throughout the duration of the project. At a minimum, the project plan should contain the following four elements: an abstract or overview, technical design and specifications, schedule, and budget.

1. The **abstract** should summarize the project to facilitate communication to interested parties.

2. The **technical design** should clearly and specifically:

    - State project objectives and identify output products.
    - State the methods and data sources to be used.
    - Break the workload into identifiable tasks.
    - Estimate hours and type of personnel and skills by task.
    - Estimate resource needs including costs, personnel, and equipment needed by task.
    - Identify material and services needed by task.
    - Assess risk of failure by task and provide contingency plans for high-risk tasks.
    - State the data standards to be followed.

- Include a quality control process and accuracy requirements.

The breakdown of tasks in the technical design is particularly important. Tracking individual tasks is much easier than trying to manage the whole project at once. The task breakdown is also used to monitor progress and budget. Assessing risks and formulating contingency plans are also important to the technical design. Typical risks for vegetation mapping projects include:

- Problems related to using new or untried technology.
- Chances that primary data for certain geographic area(s) are not available.
- Chances of delay in acquiring imagery or other data.
- Budget and schedule overruns.
- Problems related to the logistical challenges of fieldwork.
- Training or hiring of skilled personnel.
- Failure to meet specified accuracy standards.

3. The project **schedule** is constructed from the technical design as follows:

- Start with the time needed for each task as listed in the technical design.
- Determine which tasks are concurrent and which are sequential.
- Consider the availability of personnel.
- Consider constraints related to fieldwork, access to computers, and availability of data.
- Include time for contingency plans.
- Develop the final schedule.

4. The project **budget** is calculated by assigning costs to each task identified in the technical design. Be sure to include salaries, travel and training costs, equipment and material needs, and required outside services, as well as personnel time.

3.22 Map Standards

In this section:

- ***Requirements for map unit keys (3.221)***
- ***Definition of standard map attributes (3.222)***
- ***Thematic map accuracy requirements (3.223)***
- ***Minimum map feature (3.224)***
- ***Spatial map accuracy requirements (3.225)***
- ***Map update cycles (3.226)***

3.221 Map Unit Keys

Prior to developing the map, classification schemes for each of the map unit standards and any additional data attributes must be developed. Map keys define mutually exclusive map units within each classification scheme. Map units should be clearly identifiable through the mapping process and on the ground. Physiognomic and floristic map keys should reference the appropriate information source specific to the mapping project (*i.e.*, all vegetation associations used to define the desired map units). Map keys must also contain specific logic for defining and differentiating each physiognomic, floristic, and structural map unit.

3.222 Map Attributes

Existing vegetation maps are based on the areal extent of the map features and the associated physiognomic and floristic composition attributes as well as attributes for structural characteristics. This guide identifies vegetation characteristics that are common to many of the business needs previously identified. The following four attributes are standard for the base, mid, and broad levels. Additional attributes may be necessary to meet local information needs and will be defined by regional and/or forest program managers. Locally specific standards will apply across their logical geographic extents to ensure data consistency.

Physiognomic and Floristic Composition Attributes

Physiognomic and Floristic Composition**--**Physiognomic and floristic composition are the most fundamental components of a vegetation map. The National Vegetation Classification (NVC) (FGDC 1997) has defined a hierarchical system for arranging these components into taxonomic units, which is the foundation for the map hierarchy described in this guide. When the NVC was adopted as an FGDC standard in 1997 the document provided the description of both the physiognomic and floristic composition components. Two floristic levels, alliances and associations, were defined. Standards were provided for only the physiognomic portion of the hierarchy. To further develop standards for the NVC the Ecological Society of America (ESA), through a memorandum of understanding with the FGDC, established a vegetation classification panel (ESA 1999). In May 2002 the ESA vegetation panel submitted Standards for Associations and Alliances of the U.S. National Vegetation Classification (Jennings et al. 2002). The ESA document states as follows. “Consistent with FGDC principles, the standards here for floristic units relate to vegetation classification and are not standards for the identification of mapping units. Nevertheless, types defined using these standards can be mapped and can be used to design useful map units subject to the limitations of scale and mapping technology.” The ESA proposed standards for associations and alliances along with the physiognomic standards in the 1997 U.S. National Vegetation Classification form the basis for the mapping standards identified in this technical guide. It is assumed that all map units will fit somewhere within this hierarchy, whether or not they are included in the FGDC classification**.**

Landscape features dominated by land uses (*e.g.*, urban areas) and water bodies are to be mapped as non-vegetative, if they are less than the minimum standard for vegetative cover. Mapping continuous areas requires using land use and cover as well as vegetation classification systems. While many areas of the National Forests could be mapped using map units defined by vegetation physiognomic classification only, sparsely vegetated and non-vegetated areas mapped solely as such, give little information to the map user. The additional assignment of land cover labels such as water, barren land, or snow, would be more informative. Urban and agricultural land use dominated areas will classify, more often than not, as vegetated condition. While land use can be mapped for vegetative conditions alone, having additional information related to the land use allows map users the ability to answer questions such as the amount and location of urban forests or agricultural vineyards. See appendix 3G for an illustration of the intersection between land use/land cover and physiognomic class and subclass.

Each map level has a minimum required degree of compositional detail. The least required detail is at the national level and greatest is at the base level. At a minimum, the most detailed classification of map units must equal or exceed the least detailed required map unit at the next level up in the map hierarchy. As an example, table 3.3A lists dominance type as the most detailed floristic category required for the mid-level, while the base level requires more detailed alliances. This ensures that a given map product will aggregate up to the next level and still meet the required compositional detail at that level. At each level in the map hierarchy, every category above the lowest required category is also required.

Floristic map units based on vegetation types from a fully documented and adopted existing vegetation classification system are required by the standard. However, it is recognized that the near term availability of adopted FGDC vegetation classifications may limit the ability to develop floristic map units. Additionally, identified business needs may influence the level of floristic detail defined in the map key. Technological limits and resource constraints also may preclude the development of the full range of taxonomic units identified to meet business requirements. In all cases, map units and associated keys must reference the classification system documents on which they were based. Where an adopted FGDC existing vegetation classification system exists, but map detail is more generalized, floristic map units should be based on and referenced to that classification system.

Tables below (Tables 3.3a-d and 3.4) identify the hierarchical categories of physiognomic and floristic composition that are required (R) or optional (O) for each level of map product. An example of classes for the listed attributes of the hierarchy follows. The source for physiognomic categories is FGDC document FGDC-STD-005 - Vegetation Classification Standard, located at www.fgdc.gov/standards/status.

Continuous Land Cover Mapping and Land Use Classes--Landscape features dominated by land uses (*e.g.*, urban areas) and water bodies are mapped as non-vegetated within the physiognomic hierarchy, if they are less than the minimum standard for vegetative cover. However, mapping continuous areas requires using land use and cover as well as vegetation classification systems. For this reason land cover and land use classes defined in the Anderson 1 classification system (Anderson et al. 1976) are required for non-vegetated areas. While many areas of the National Forests could be mapped using map units defined by vegetation physiognomic classification only, sparsely vegetated and non-vegetated areas mapped solely as such give little information to the map user. Land cover labels such as water, barren land, or snow are more informative and allow for the most integrated representation of vegetated and non-vegetated landscapes.

Land-use labels within vegetated polygons are not a required component of the mapping protocol; however, information needs may dictate the co-development of land-use and existing vegetation map labels. Urban and agricultural land use dominated areas will classify, more often than not, as a vegetated condition. While many land uses can be mapped for their vegetated conditions alone, having additional information related to the land use allows map users the ability to answer questions such as the amount and location of urban forests or agricultural vineyards. See appendix 3G for an illustration of the intersection between land use/land cover and physiognomic class and subclass.

Table 3.2 depicts a simplified relationship between the Anderson 1 land use/land cover classification system and physiognomic classes.

Table 3.2. Relationship Between Anderson 1 and FGDC Physiognomic Class

	Anderson 1 Land Use Land Cover								
FGDC Physiognomic Class	Urban or Build-up land	Agricult-ural land	Range-land	Forest-land	Water	Wetland	Barren land	Tundra	Perennial Snow or Ice
Closed tree canopy - Forest	**X**	**X**		**X**		**X**			
Open tree canopy - Savannah	**X**	**X**		**X**		**X**			
Shrubland	**X**	**X**		**X**		**X**		**X**	
Dwarf shrubland	**X**		**X**			**X**		**X**	
Herbaceous - Shrub Steppe	**X**	**X**	**X**			**X**		**X**	
Herbaceous Grassland	**X**	**X**	**X**			**X**		**X**	
Non-vascular						**X**	**X**	**X**	
Sparsely Vegetated	**X**	**X**					**X**		
Non-Vegetated	**X**				**X**		**X**		**X**

Note: Herbaceous – Shrub Steppe is added as a Forest Service addition to the NVC.

Physiognomic Classes--Tables 3.3A through 3.3D identify the NVC physiognomic levels that are required attributes at each mapping level.

Table 3.3A. Physiognomic Map Attributes

Physiognomic Classification Category	**Map Level**			
	National	Broad	Mid	Base
Physiognomic Order*	*R*	*R*	*R*	*R*
Physiognomic Class**woody vascular plants (tree/shrub) required, herbaceous and non-vascular optional*	*R*	*R*	*R*	*R*
Physiognomic Sub-class**woody vascular plants (tree/shrub) required, herbaceous and non-vascular optional*	*O*	*R*	*R*	*R*

*Reflects NVC physiognomic hierarchy with modifications necessary to meet the Forest Service business requirements (refer to section 1.515 for discussion).

Note: R=required, O=optional

Table 3.3B. Physiognomic Classes-Order

NVCS Order - Vegetated Division	
name	*definition*
tree dominated order	Areas where tree life form (NRCS plants growth habit) has at greater than or equal to 10 percent cover in the uppermost strata during the peak-growing season.
shrub dominated order	Areas where shrub and or subshrub life forms are greater than or equal to 10 percent cover in the uppermost strata.
NVCS Order – Vegetated Division	
name	*definition*
herbaceous/non-vascular dominated order	Areas where herbaceous and/ or non-vascular life forms are greater than or equal to 10 percent cover in the uppermost strata.
no dominate life form order	Areas where vegetation cover is greater than or equal to 1 percent, but the area does not classify as tree, shrub or herbaceous/non-vascular dominated.
NVCS Order – Non-vegetated Division	
non-vegetated order	Non-vegetated usually associated with open water or land use dominated, man modified land such as heavy industrial, commercial, and transportation facilities

Table 3.3C. Physiognomic Classes-Class

NVCS Class – Vegetated (as modified by NFS for minimum life form cover requirements)	
Tree Dominated Order	
name	*definition*
closed tree canopy	Tree life form dominated land with greater than or equal to 60 percent canopy crown closure. Tree life form is defined by NRCS Plants Master growth habit for tree.
open tree canopy	Tree life form dominated land with greater than or equal to 25 percent but less than 60 percent canopy crown closure. Tree life form is defined by NRCS Plants Master growth habit for tree.

Table 3.3C. Physiognomic Classes-Class (continued)

NVCS Class – Vegetated (as modified by NFS for minimum life form cover requirements)	
Tree Dominated Order	
sparse tree canopy	Tree lifeform dominated land with greater than or equal to 10 percent but less than 25 percent canopy crown closure. Tree life form is defined by NRCS Plants Master growth habit for tree. *This class is a Forest Service addition to NVCS Order.*
Shrub Dominated Order	
shrubland class	Tall shrub life form dominated land with greater than or equal to 10 percent cover. Less than 10 percent tree cover may be present.
dwarf shrubland class	Subshrub life form dominated land with over 10 percent cover of subshrubs. Less than 10 percent tree and or tall shrub cover may be present.
Herbaceous and Non-vascular Dominated Order	
herbaceous – shrub steppe class (optional)	Herbaceous life form dominated land with greater than or equal to 10 percent cover, and shrub and or sub-shrub life form of greater than or equal to 5 but less than 10 percent cover. *This class is a Forest Service addition to NVCS Order.*
herbaceous – grassland class	Herbaceous life form dominated land with greater than or equal to 10 percent cover. Tree, shrub and or subshrub life forms must be less 10 percent cover.
Herbaceous and Non-vascular Dominated Order	
non-vascular class (optional)	Non-vascular life form dominated land with greater than or equal to 10 percent cover. Tree, shrub, sub-shrub, and grass life forms must be less than 10 percent cover.
No Dominate Life Form Order	
sparsely vegetated class	Total vegetative cover greater than or equal to 1 percent but less than 10 percent. Vegetation is scattered or nearly absent, total vegetation cover, excluding crustose lichens (which can sometimes have greater than 10 percent cover) is generally 1 to 10 percent.

Table 3.3D. Physiognomic Classes-Subclass

NVCS Subclass – Vegetated	
Subclass for Tree, Shrub and Subshrub Dominated Classes	
name	*definition*
evergreen vegetation subclass	Evergreen vegetation associations in which evergreen plants generally contribute 75 percent or more to the total dominate plant cover. Evergreen species are woody plant species that have green leaves all year round or a plant that in xeric habitats has green stems or trunks and never produce leaves.

Table 3.3D. Physiognomic Classes-Subclass (continued)

NVCS Subclass – Vegetated	
Subclass for Tree, Shrub and Subshrub Dominated Classes	
deciduous vegetation subclass	Deciduous vegetation associations in which deciduous woody plants generally contribute 75 percent or more to the total dominate plant cover. Deciduous species are woody plants that seasonally lose all of its leaves and becomes temporarily bare-stemmed.
mixed evergreen-deciduous vegetation subclass	Mixed evergreen-deciduous vegetation which evergreen and deciduous species each generally contribute 25-75 percent of the total canopy cover.
Subclass for Herbaceous Dominated Classes	
perennial graminoid subclass (optional)	Perennial graminoid vegetation associations, graminoids that persist for several years a species, generally contributing too greater than 50 percent of the herbaceous vegetation.
perennial forb subclass (optional)	Perennial forb vegetation associations, forbs (including ferns and biennials) that persist for several years and species, generally contributing to greater than 50 percent of the herbaceous vegetation.
annual graminoid and or forb subclass (optional)	Annual vegetation associations that persist for less than one year, or are dominated by annual species.
hydromorphic rooted vegetation subclass (optional)	Hydromorphic rooted vegetation of non-emergent graminoids or forbs, structurally support by water, and rooted in substrate (*e.g.*, pond weeds and water lilies).
Subclass for Non-vascular Dominated Classes	
bryophyte subclass (optional)	Bryophytes (including mosses, hornworts, and liverworts) vegetation generally dominates the nonvascular cover.
lichen subclass (optional)	Lichens (foliose or fruticose) generally dominate the nonvascular cover.
alga subclass (optional)	Algae generally dominate the nonvascular cover.
Subclass for Sparsely Vegetated Classes	
consolidate rock subclass (optional)	Consolidated rock with sparse vegetation, such as cliffs, outcrops, lava flows, bedrock.
boulder, gravel, cobble or talus subclass (optional)	Tallus/scree slopes, rock flats of boulders, cobble or gravel with sparse vegetation.
unconsolidated material subclass (optional)	Unconsolidated material (soil, sand, and ash) such as sand dunes, sand flats, sand beaches and shores, agriculture field-bare soil, non-agriculture disturbed areas, tidal mud flats
urban or build-up subclass (optional)	Meets Anderson Level 1 land use classification for urban and built-up land, but has sparse vegetation. Residential buildings, commercial and industrial complexes, transportation and utilities, paved over areas.

Floristic Composition--Floristic composition is a fundamental attribute of existing vegetation maps comprised of associations and alliances. Alliances and associations are classification standards, not map unit standards for the labeling of map features.

Nevertheless, vegetation alliances and associations, defined using classification standards, can be used to design map units subject to the limitations of scale and mapping technology (Jennings et al. 2002).

The association is the most basic unit of vegetation in the NVC. The NVC defines an association as "a recurring plant community with a characteristic range in species composition, specific diagnostic species, and a defined range in habitat conditions and physiognomy or structure" (Jennings et al. 2002). Since the delineation of associations requires identification of understory species that are not present in the upper canopy, their direct use is appropriate only where the mapping effort includes extensive ground observations.

The National Vegetation Classification Standard (NVCS) specifies that floristic alliances are abstract units of vegetation determined by both the floristic characteristics shared among associations and the physiognomic-ecological characteristics of the higher levels of the classification. Thus, the alliance is defined as follows: A grouping of associations with a characteristic physiognomy and habitat and which share one or more diagnostic species that, as a rule, are found in the uppermost or dominant stratum of the vegetation.

The development of existing vegetation map units based on NVCS require the availability of alliance descriptions, based on verified associations, developed from appropriate field plot data as described in section 2 of this technical guide and is required for base level mapping. Because the ESA proposed standards for associations and alliances have not been formally adopted as part of the NVC, it will likely be many years before a comprehensive set is available across the country to serve as a basis for map unit design. To ensure that existing vegetation maps meet FGDC standards, verified, peer reviewed associations and derived alliances should be used for the development of map units.

Interim approaches exist for defining existing vegetation map units within the guiding principles of the NVC. These approaches for mid-level mapping include the use of provisional associations and alliances maintained in the NatureServe classification database (NatureServe 2001) with key components available on the NatureServe web site (www.natureserve.org/explorer), as well as regionally developed dominance type classification systems. Other acceptable alternatives for broad-level mapping, include the use of cover types including the Society of American Foresters (SAF) (Eyre 1980) forest types and the Society for Range Management (SRM) (Shiftlet 1994) cover types to develop the floristic characteristics of map units.

Dominance types have been widely used in the development of map units where remote sensing imagery is the primary basis for map feature delineation. "Under the dominance approach, vegetation types are classified on the basis of dominant plant species found in the uppermost stratum. Determining dominance is relatively easy, requiring only a modest floristic knowledge. However, because dominant species often have a geographically and ecologically broad range, there can be substantial floristic and ecologic variation within any one dominance type."…" "Dominance types" provide a simple method of classification based on the floristic dominant (or group of closely related dominants) as assessed by some measure of importance such as biomass, density, height, or leaf-area cover (Kimmins 1997). They represent one of the lowest levels in several published classification hierarchies (*e.g.*, Cowardin *et al.* 1979, Brown *et al.* 1980). (ESA 2002)"

""Cover types" are typically based on the dominant species in the uppermost stratum of existing vegetation. Forest cover types developed by the Society of American Foresters (SAF) are based on the tree species which may by one or more species, having a plurality of basal area as measured from ground plots (Eyre 1980)." For rangelands, the Society of Range Management's (SRM) recently developed cover types are based on the plurality of canopy cover by dominant species (Shiftlet 1994).

In most cases the map unit descriptions will be parallel to the classification hierarchy established as stated in the ESA Vegetation panel report (Jennings *et al*. 2002). In this guide, these will be referred to as "homogenous type" map units. However, as Jennings and others (2002) have suggested, "It is important to remember that, while vegetation varies continuously in time and space, classification partitions that continuum into discrete units, primarily for practical reasons. …[Map unit design] approaches, particularly those that aggregate alliances and associations using vegetation physiognomy as criteria may be more practical for some uses. For example, in using the NVC Alliance class as a target for vegetation mapping by the Gap Analysis Program (Jennings 2000), not all alliance types can be resolved. In such cases alliance types are aggregated into map units of "compositional groups" or "ecological complexes" Although not part of the NVC standard, such alternative approaches would result in units of vegetation that are just as "legitimate"." It is anticipated that similar situations may arise as the Forest Service attempts to implement mapping standards based on the NVC. In this guide the term vegetation complexes will be used as analogues to ecological complexes.

Homogenous types are map units composed of a homogenous condition of vegetation or uniform type, a map unit composed of a single alliance or dominance type, at least 85% of the area within polygon.

Compositional groups are map units composed of alliances or dominance types that are spatially discrete but cannot be discriminated into separate map units by spectral signatures or landscape indices such as slope, aspect, and elevation. For example, in the southern United States compositional groups have been proposed in the Gap Analysis Project (GAP) to accommodate mixed vegetation dominated by southern yellow pine.

Vegetation complexes are map units distinguished from compositional groups in that the spatial closeness of the alliances or dominance types prevents discrimination of separate map features. In North Carolina, for example, pocosin wetlands are spatially heterogeneous with pond pine woodlands intermixed with several evergreen shrubland alliances in such close proximity that they cannot be delineated separately yet form ecologically and spatially repeating patterns across the landscape.

Mapping units developed from the NVC apply to all existing vegetation regardless of successional stage or cultural influence. In many areas of the country, forests and other wild land environments may be intermixed with agricultural lands, recreational developments and other developed areas where the vegetated cover meets the standards for mapping existing vegetation. Descriptions of these vegetative cover types are not included or are poorly represented in the NVC provisional associations and alliances or the SAF cover types. Some of these cover types may be included in SRM cover type descriptions. In many cases, existing vegetation map units will have to be defined to describe these portions of the landscape. Map unit descriptions will also need to be developed for areas where the extent of emergent aquatic vegetation or an exotic plant species is dominant and covers an area in excess of extent identified for a minimum map feature.

Table 3.4. Floristic Map Attributes

Floristic Classification Category	**Map Level**			
	National	Broad	Mid	Base
Cover Types and Type Groups (SAF/SRM)	*O*	*R*	*R*	*R*
Dominance Types (locally defined)	*O*	*O*	*R*	*R*
Alliances*	*O*	*O*	*O*	*R*
Associations*	*O*	*O*	*O*	*O*

*Currently defined levels of the NVC hierarchy (refer to section 1.515 for discussion)

Note: R=required, O=optional

The following example illustrates map units and attributes within a map feature from the top of the hierarchy downwards.

DIVISION: Vegetated
ORDER: Tree Dominated
CLASS: Closed Tree Canopy
SUBCLASS: Evergreen Forest
COVER TYPE (SAF): Douglas-fir
DOMINANCE TYPE (R5-CALVEG): Douglas-fir
ALLIANCE: Douglas-fir Forest – Bigleaf Maple
ASSOCIATION: Douglas-fir – Bigleaf Maple-Hazelnut

Structural Characteristic Attributes

Tree Canopy Closure**--**Tree canopy closure is defined here as the total non-overlapping tree canopy in a delineated area as seen from above. (Note: Tree canopy closure **is not** defined by a hemispherical projection as seen from below.) Tree canopy closure below 10% is considered a non-tree polygon. Table 3.5 identifies tree canopy closure breaks that are required for base-, mid-, and broad-level maps. Canopy closure breaks at 10% (base level) represent feasibly mapped approximations of a continuous canopy variable and offer the greatest flexibility for user specified aggregation. The tree canopy closure breaks are consistent with the physiognomic class breaks for vegetation. Any further divisions necessary to meet local requirements must be subdivisions of the categories listed in the table.

Table 3.5. Total Tree Canopy Closure Map Units

Canopy Closure Categories	Map Level			
	National	Broad	Mid	Base
0%				*R*
1-9.9%		*R*	*R*	*R*
10-19.9%				*R*
20-29.9%			*R*	*R*
30-39.9%				*R*
40-49.9%	*O*	*R*	*R*	*R*
50-59.9%				*R*
60-69.9%				*R*
70-79.9%		*R*	*R*	*R*
80-89.9%				*R*
90-100%				*R*

<u>Overstory Tree Diameter Map Units</u>-- Overstory tree diameter class is defined here as *any of the intervals into which a range of tree diameters may be divided for classification* (Helms 1998). *In this protocol the mean diameter at breast height (4.5 ft. 1.37 m. above the ground) is calculated for the trees forming the upper or uppermost canopy layer* (Helms 1998). Note: this mean can be calculated as the Quadratic Mean Diameter (QMD) or as basal area weighted mean diameter. Table 3.6 identifies tree diameter class breaks that are mandatory for base- and mid-level mapping. Developing tree size map units at the broad- and national-level is optional. Additional categorical breaks necessary to meet local requirements, within the mid and base levels, must aggregate to the standard tree diameter categories.

Table 3.6. Overstory Tree Diameter Map Units

Diameter Categories (inches/dbh)	Map Level			
	National	Broad	Mid	Base
0-4.9			*R*	*R*
5-9.9			*R*	*R*
10-19.9			*R*	*R*
20-29.9	*O*	*O*	*R*	*R*
30-39.9				*R*
40-49.9			*R*	*R*
50+				*R*

3.223 Thematic Accuracy

Accuracy assessments of the defined map attributes should be conducted as a standard part of the mapping process. These assessments should focus on the thematic content of the map and are not required to determine spatial accuracy of map feature delineations. The spatial accuracy standards addressed under the **Georegistration** section (Section 3.225) should be applied primarily to the data sources used to develop the maps, and are not part of a thematic accuracy assessment.

Accuracy standards are addressed at two levels: 1) minimum accuracy required for a national corporate vegetation layer, and 2) ideal accuracy goals based on what can feasibly be obtained. It is recognized that increased floristic and structural categorical detail and/or increased mapping difficulty usually results in a higher probability of map error. Realistic accuracy standards account for the degree of difficulty in mapping due to the nature and detail of each attribute. As an example, physiognomy is less detailed and considered less difficult to map than the other map attributes and, therefore, has higher accuracy standards associated with it. Mapping feasibility, however, does not take precedence over the need for accuracy standards that ensure a useful product. Map attributes, required and optional, that do not achieve the minimum accuracy standard should populate a national corporate database structure. However, the inability to achieve the accuracy standards does not require the disposal of map products that are the result of significant investment.

An objective evaluation of map accuracy results will illustrate the nature and magnitude of map error. A process should then be identified to improve accuracy on substandard map units. Documentation may also be necessary to alert users to limited utility that may exist as a result of low accuracy. A map improvement process will be comprised of one or more approaches including re-mapping and re-design of the map units. Re-mapping should logically target the map attributes or map units in question and may require a change in mapping methodology. Re-designing map units based on mapping feasibility also provides an opportunity to achieve accuracy standards (*see Ken's map unit design discussion*), typically through class aggregation. However, it should be recognized that aggregating classes to map units that are broader than the standard for the desired map level, effectively represents a shift to a coarser map level. It is conceivable that a map product will not meet the accuracy standards uniformly for a given map level. In a hypothetical example, a map meets base level standards for tree canopy closure but only achieves floristic accuracy standards for dominance types. In such a case the map would be considered a mid level map that exceeds the minimum standard for tree canopy closure.

Several approaches can be used to determine map accuracy, some of which are subsequently discussed in section 3.224 under thematic accuracy. The assessment method(s) used should be documented and the results of all methods reported. The basis for determining compliance with the accuracy standards will be, by default, a standard error matrix unless otherwise stated in the accuracy assessment documentation. Regional vegetation data stewards will need to determine the adequacy of a given accuracy assessment method for determining standards compliance.

Table 3.7 lists accuracy goals and standards for the required data attributes at each map level. Accuracy percentages refer to overall weighted accuracy for each map attribute.

Table 3.7. Map Attribute Accuracy Goals and Requirements

Vegetation Map Attribute	Map Level			
	National goal-standard	Broad goal-standard	Mid goal-standard	Base goal-standard
Physiognomic Order	80%-70%	90%-80%	90%-80%	90%-80%
Physiognomic Class	80%-70%	90%-80%	90%-80%	90%-80%
Physiognomic Sub-class		90%-80%	90%-80%	90%-80%
Alliance		80%-65%	85%-65%	85%-65%
Association		80%-65%	85%-65%	85%-65%
Cover Type		80%-65%	85%-65%	85%-65%
Dominance Type		80%-65%	85%-65%	85%-65%
Tree Canopy Closure		80%-65%	85%-65%	80%-65%
Tree Diameter Class			80%-65%	80%-65%

3.224 Minimum Map Feature

Minimum map feature is the term used to describe the smallest size polygon required in a map. A homogeneous area must be delineated in a map if it is equal to or greater in areal extent than the minimum map feature standard for each map level. Stated in another way, no differing condition, as defined by the map unit design, greater in area than the minimum map feature can be left as an unmapped inclusion in a larger polygon. Depending on technical feasibility and business need, it may be necessary to map features smaller in areal extent than the minimum map feature standard.

Table 3.8 defines the minimum map feature standard for each of the map levels.

Table 3.8. Minimum Map Feature Standard

	Map Level			
	National	Broad	Mid	Base
MMU (acres)	500	20	5	5

3.225 Georegistration

Each level of the map hierarchy is intended to cover a general analysis scale and/or business function area. Correspondingly, a measure of spatial precision and accuracy is implied at each level. Spatial precision is generally determined by the data sources and methods used to develop a map. Guidelines for appropriate data sources and methods are outlined in section 3.24. Map scale equivalencies are established for each map level (*i.e.*, base = 1:24000, mid = 1:100000, *etc.*). The geospatial positioning accuracy of imagery and ancillary datasets used to derive the existing vegetation maps should be obtained from the data provider. The geospatial positioning accuracy of intermediate and final geospatial datasets produced during the development of an existing vegetation map and any input datasets shall be calculated according to the standard defined in Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data (FGDC-STD-007.3-1998). The National Standard for Spatial Data (NSSDA) is a data usability standard that defines the process for calculating and reporting the geospatial positioning accuracy of the data. The data producer is required to determine and report the accuracy of their datasets and report it according to NSSDA. The NSSDA uses root-mean-square error (RMSE) at the 95% confidence level to determine positional accuracy of datasets in ground units. The accuracy shall be tested by comparing the planimetric coordinates of a minimum of 20 well-defined points in the dataset with coordinates of the same points from an independent source of higher accuracy. In cases where it is not possible to determine the positional accuracy of a dataset by the prescribed procedure the NSSDA identifies three alternatives for determining positional accuracy: deductive estimate, internal evidence, and comparison to source. The use of these alternatives is most appropriate for estimating the positional accuracy of ancillary datasets from external sources. These alternatives should not be used to determine the positional accuracy of the primary imagery sets used in producing existing vegetation maps. Digital orthophotos are generally the best source of control points for assessing the accuracy of existing vegetation maps. The horizontal geospatial positioning accuracy standards for existing vegetation maps (datasets) are identified in Table 3.9.

Table 3.9. Horizontal Accuracy Requirements

	Map Level			
	National	Broad	Mid	Base
Map Scale	1:1000000	1:250000	1:100000	1:24000
Horizontal Accuracy	+/-1666 ft	+/-416 ft	+/-166 ft	+/-40 ft

3.226 Update Schedule

Vegetation composition and structure are dynamic and changes in vegetation regularly necessitate the refreshment of existing vegetation maps. Each map level has an associated temporal scale that determines the frequency of map maintenance. Within the extent of the time identified, a given map product will be updated to account for changes in vegetation that have typically resulted from sudden disturbance such as fire, insect and disease caused mortality, silvicultural treatments, rapid growth, *etc.* Gradual successional changes are more difficult to identify and may need to be accounted for over longer time frames. Further discussion of map maintenance is found in section 3.43.

Business needs and resource constraints will also play a role in determining the update cycle. A time range is listed for each map level to allow for flexibility in planning map maintenance. Map products that have a hierarchical relationship should be on a coordinated schedule to ensure that updates in the most detailed map are incorporated into upper level maps in a timely fashion. Table 3.10 lists the temporal scale or update period for each map level.

Table 3.10. Map Update Frequency

	Map Level			
	National	Broad	Mid	Base
Temporal Scale	5-10 years	5-10 years	1-5 years	1-5 years

3.227 Metadata

FGDC compliant metadata will accompany map products developed at each level of the hierarchy. Further discussion on metadata content and format is located in section 3.4.

3.23 Map Design

In this section:
- ***The process for designing map units based on physiognomic, floristic, taxonomic units and structural technical groups***
- ***Determining map feature size and delineation method***

Map design involves two fundamental processes. The first process, map unit design, identifies the vegetation characteristics to be mapped and assembles or develops classification keys for each of the map attributes used to describe those characteristics. This process establishes the relationship between vegetation classification and mapping. The second process, map feature design, identifies the spatial characteristics and structure of the map. These processes are implemented to comply with vegetation map standards and adopted vegetation classifications. To illustrate these process relationships hypothetical examples are provided in section 3.233.

3.231 Map Unit Design

As discussed in section 1.32, the relation of vegetation classification to mapping provides the basis for map unit design. **Classification** *is the process of grouping of similar entities together into named types or classes based on selected shared characteristics* (more detailed discussion of the nature of vegetation classification is included in section 1.31). **Vegetation mapping** *is the process of delineating the geographic distribution, extent, and landscape patterns of vegetation types and/or structural characteristics* . Patterns of vegetation types cannot be recognized until the types have been defined and described. Consequently, consistent mapping of vegetation types requires that a vegetation classification be developed beforehand. Any mapping based on vaguely defined types will be inconsistent, hard to validate, and difficult to compare with other vegetation maps.

The mapping standards for existing vegetation defined in this section include five types of classifications. The physiognomic and vegetation type classifications are based on floristic characteristics while the total vegetation canopy cover, tree canopy cover, and tree size classifications are based on structural characteristics. The physiognomic type and vegetation type classification systems consists of associated sets of **taxonomic units** that are the basic set of classes or types that comprise the classification systems. Similarly, the total vegetation canopy cover, tree canopy cover, and tree size classifications consist of associated sets of **technical groups** that are the basic sets of classes or that comprise the classification systems. Taxonomic units and technical groups represent a conceptual description of ranges and/or modal conditions in vegetation characteristics. These taxonomic units and technical groups should provide the basis for vegetation maps that are consistent with the mapping objectives, appropriate for the map level being produced, and within the limitations of mapping technology. Establishing the relationship between these vegetation classifications and map products depicting them is accomplished through the **map unit design** process.

A **vegetation map unit** is *a collection of areas defined and named the same in terms of their component taxonomic units and/or technical groups* (adapted from Soil Survey Division Staff 1993). These vegetation map units can be based on the taxonomic units and technical groups of physiognomic, floristic, or structural classifications or on combinations of these. Map units are designed to provide information and interpretations to support resource management decisions and activities. The map unit design process establishes the criteria used to aggregate or differentiate vegetation taxonomic units and technical groups to establish corresponding map units. Therefore, a mapping unit is comprised of one or more taxonomic units and/or technical groups from one or more specific classifications. The criteria used to aggregate or differentiate within physiognomic types, vegetation types, or structural classes to form mapping units will depend on the purpose of, and the resources devoted to, any particular mapping project (Jennings *et al*. 2002). For example map units designed to provide information on existing forest structure to characterize wildlife habitat or fuel condition would be based on a combination of tree canopy cover technical groups and overstory tree diameter technical groups. The map unit design process is more complex for floristic classifications than for relatively simple structural classifications. The mapping standards for vegetation cover, tree canopy closure, and tree diameter described in this section represent general-purpose map unit designs for each structural classification at all map levels; although local information needs may occasionally require exceeding the standards.

Map units are depicted on maps within individual areas or delineations that are non-overlapping and geographically unique referred to as **map features** (*e.g.,* polygon delineations or region delineations). The map feature delineation process should be based on the map units identified in the map unit design process. Typically, one map unit is repeated across the landscape in many individual map feature delineations.

Table 3.11. Technical Group, Map Unit, and Map Feature Relationship Example

<table>
<tr><th>Total Vegetation Canopy Cover Classification</th><th></th><th>Total Vegetation Canopy Cover Mid-level Map Product</th><th></th></tr>
<tr><td>Canopy Cover Technical Groups</td><td rowspan="12">Map Unit Design Process
Converts Technical Groups into Map Units</td><td>Canopy Cover Map Units</td><td rowspan="12">Map Feature Delineation Process
Spatially Depicts Map Units</td></tr>
<tr><td>0%</td><td rowspan="2">Sparse Vegetation</td></tr>
<tr><td>1-9.9%</td></tr>
<tr><td>10-19.9%</td><td rowspan="2">10-29.9% Canopy Cover</td></tr>
<tr><td>20-29.9%</td></tr>
<tr><td>30-39.9%</td><td rowspan="3">30-59.9% Canopy Cover</td></tr>
<tr><td>40-49.9%</td></tr>
<tr><td>50-59.9%</td></tr>
<tr><td>60-69.9%</td><td rowspan="2">60-79.9% Canopy Cover</td></tr>
<tr><td>70-79.9%</td></tr>
<tr><td>80-89.9%</td><td rowspan="2">80-100% Canopy Cover</td></tr>
<tr><td>90-100%</td></tr>
</table>

Map unit design identifies the collection of map features that share a common definition and label based on their vegetative characteristics (USDA 1993). Each map unit differs, in some respect, from all others within a geographic extent. Map units are used as map attributes in a geospatial database. Map units are composed of one or more taxonomic units and/or technical groups that are differentiated in a map unit design process and characterized in map unit descriptions. Map units generalize all possible vegetation conditions to the smallest number that meets the intended analysis objectives of the map and are feasible to produce with available resources and technology. All map units of interest need to be identified to map vegetation and land cover across the landscape (Gong and Howarth 1992). Careful planning of the map unit design process is necessary in order to establish an adequate foundation for a mapping project (Lachowski *et al.* 1995).

The first logical step in map unit design is to identify taxonomic units and/or technical groups from existing classifications that pertain to each map unit. Classification keys that may have been developed as part of an existing vegetation classification should be assembled and used as the foundation for determining floristic map units. Based on the availability of adopted vegetation classifications and the validity of historical classification systems, the use of existing classification keys may be useful to map vegetation composition. In the absence of existing classification keys that meet national and regional standards, new keys will need to be developed.

Steps in the Map Unit Design Process--When a new map unit design is required to meet local analysis needs that are not met by the national standard definitions, a balance of idealized need and resource constraint must be found. Steps for achieving this balance include the following**:**

Step 1: Define the user needs. The ideal level of detail and the intended use of the data must be clearly defined.

Step 2: Identify the resources available. Consider personnel, time, budget, existing data, and management approval is the critical resources.

Step 3: Identify the source image data to be used. Be aware of the relationship between the source data and the analysis objectives and possible limitations inherent in a given data type with respect to the desired level of information. A specific consideration would be the ability or inability of an image data type to discern individual floristic categories defined in the classification scheme.

Step 4: Formalize the design of the map units. Following the design of the map units, map unit keys and descriptions are developed. The logic of the map unit design is defined in a dichotomous key for the map units. The key illustrates the hierarchical and mutually exclusive relationship of all map units. See appendix 3A for examples of map unit keys associated with several vegetation characteristics. Map unit descriptions are developed to describe the taxonomic unit composition of each map unit.

Elements of quality map unit design--At a minimum a map unit design must be:

Exhaustive: The map units that result from the design process must account for the full range of conditions of interest found within the project area. Note: In addition to the vegetation classifications addressed by this protocol, other land cover classifications needed to meet analysis objectives should be included (*e.g.*, urban, agriculture, barren, water, etc).

Mutually exclusive: Any specific vegetation condition must be assignable to one and only one map unit.

Field applicable: The logic in the map unit design needs to be applicable to field observations and/or field sampled data.

3.232 Map Feature Design

Map feature design identifies the spatial characteristics and structure of individual areas or delineations on a map. Specific map features are non-overlapping and geographically unique and may contain more than one thematic element (map units). Two key components of map feature design are setting the size of the minimum map feature and determining how the map features will be delineated. The term, minimum map feature as used in this guide, is analogous to minimum map unit (MMU) as widely used in the past. National standards for the minimum map feature at each map level have been established under section 3.22. It is recognized, however, that local business needs may dictate the delineation of smaller landscape features, such as small water bodies or riparian areas, below the size of minimum map feature standard.

Steps for Determining the Minimum Map Feature Include:

Step 1: Define the user needs. The ideal level of detail and the intended use of the data must be clearly defined.

Step 2: Identify the source image data to be used. Consider the ability or inability of the source image data to discriminate vegetation/landscape features considered important in Step 1.

Step 3: Determine the methodology to be used for feature delineation.

Methods for map feature delineation are discussed in greater detail in section 3.24.

3.233 Map Design Examples

This section provides several simple map design examples to illustrate the map unit design and map feature design process relationships.

Example 1. A mapping project is proposed where the user identifies the need for a geospatial database and map product depicting order-level physiognomic type taxonomic units. It is determined through the map unit design process that map units can be developed to directly correspond to the taxonomic units. These relationships are listed in table 3.12. Note that the taxonomic class "vegetation not dominant" is designed to also include areas with less than 1% vegetation. An illustration of map features depicting these map units is provided in figure 3.1.

Table 3.12. Physiognomic Type Classification Taxonomic Units and Map Units

Physiognomic Type Classification	**Physiognomy Map**
Order-level Taxonomic Units	**Order-level Mapping Units**
Vegetation Not Dominant	Sparse Vegetation
Tree Dominated	Tree Vegetation
Shrub Dominated	Shrub Vegetation
Herb Dominated	Herbaceous Vegetation
Nonvascular Dominated	Nonvascular Vegetation

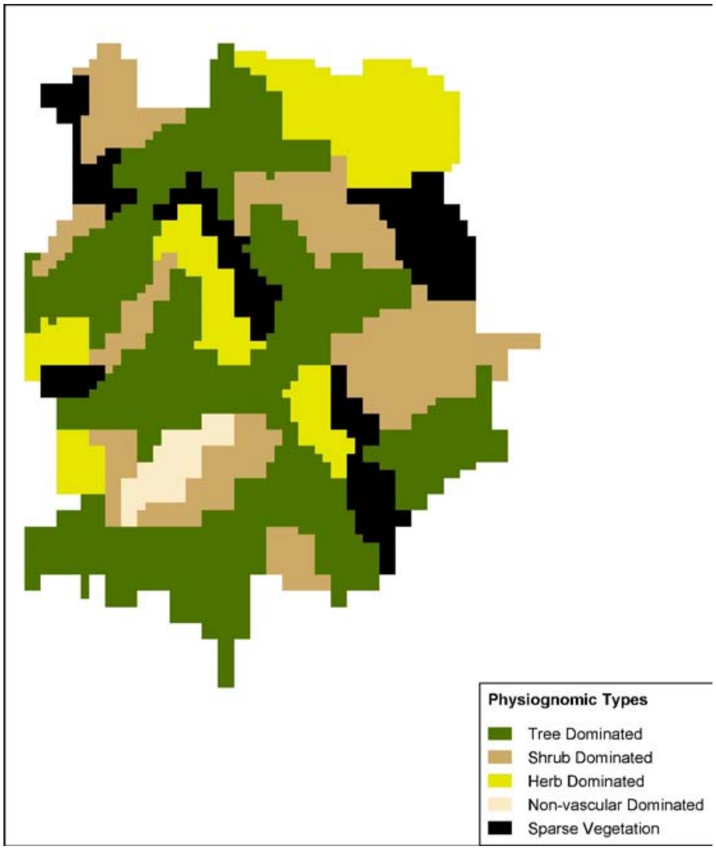

Figure 3.1. Physiognomic Types.

Example 2. A mapping project is proposed where the user identifies the need for a geospatial database and map product depicting dominance type taxonomic units. The map unit design process identifies map units that are consistent with the user needs and can be produced within the limitations of mapping technology. These relationships are listed in table 3.13. An illustration of map features depicting these map units is provided in figure 3.2.

Table 3.13. Dominance Type Classification Taxonomic Units and Map Units

Dominance Type Classification Taxonomic Units	Dominance Type Map Mapping Units
TREE SP. 1	TREE SP. 1&2
TREE SP. 2	
TREE SP. 3	TREE SP. 3
SHRUB SP. 1	SHRUB SP. 1
SHRUB SP. 2	
HERBACEOUS SP. 1	HERBACEOUS SP. 1&2
HERBACEOUS SP. 2	
NON-VASCULAR SP. 1	NON-VASCULAR SP. 1&2
NON-VASCULAR SP. 2	
SPARSE VEGETATION	SPARSE VEGETATION

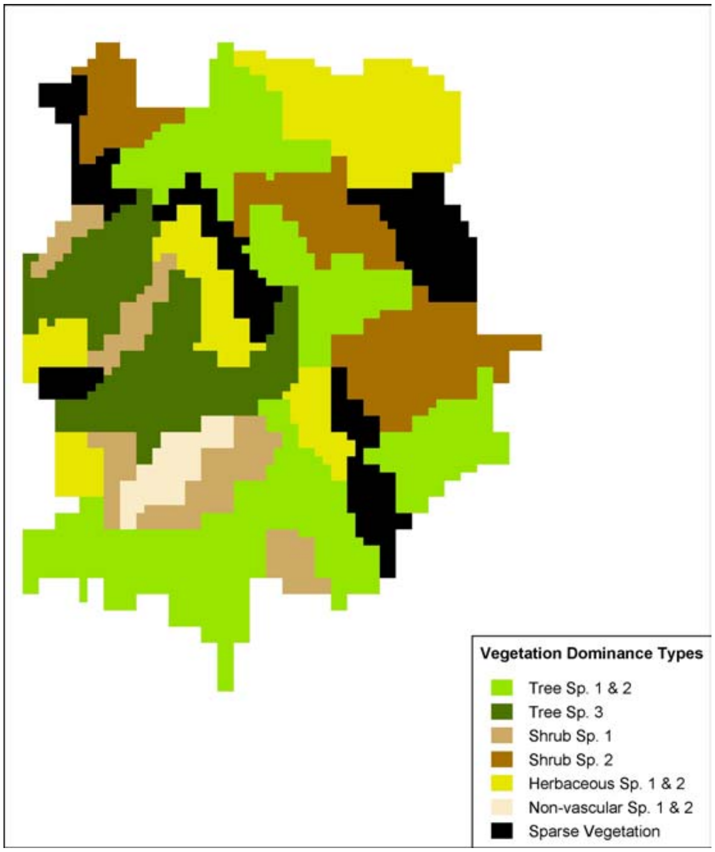

Figure 3.2. Dominance Types.

Example 3. A mapping project is proposed where the user identifies the need for a geospatial database and map product depicting tree canopy cover technical groups. The map unit design process identifies the mid-level map units defined by this protocol as appropriate for the user needs and consistent with current mapping technology. These relationships are listed in table 3.14. An illustration of map features depicting these map units is provided in figure 3.3.

Table 3.14. Tree Canopy Cover Classification Technical Groups and Map Units

Tree Canopy Cover Classification	**Tree Canopy Cover Map**
Tree Canopy Cover Technical Groups	**Tree Canopy Cover Mapping Units**
0%	Sparse Vegetation
1-9.9%	
10-19.9%	10-29.9% Canopy Cover
20-29.9%	
30-39.9%	30-59.9% Canopy Cover
40-49.9%	
50-59.9%	
60-69.9%	60-79.9% Canopy Cover
70-79.9%	
80-89.9%	80-100% Canopy Cover
90-100%	

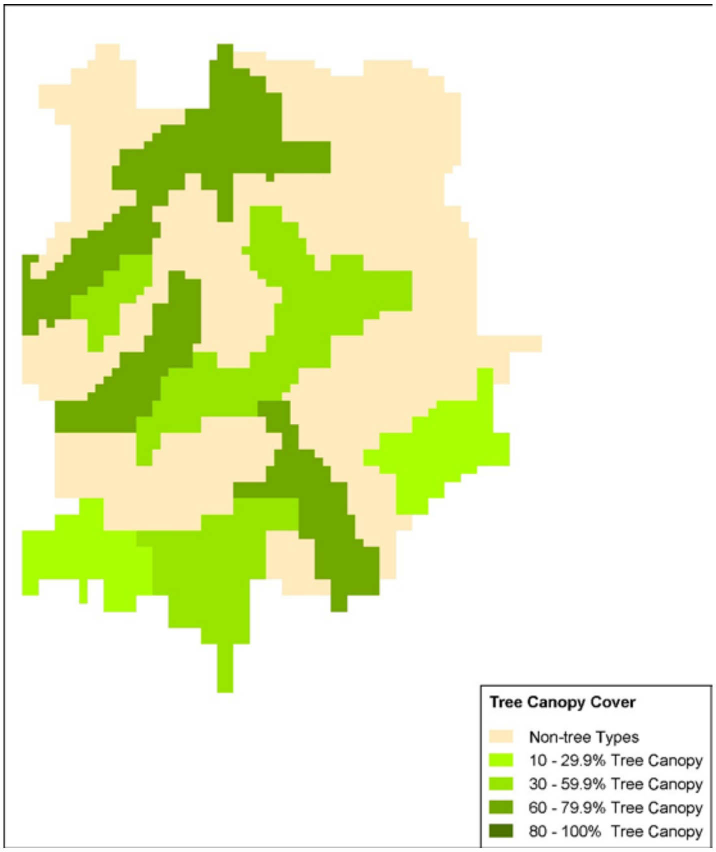

Figure 3.3. Tree Canopy Cover.

Example 4. A mapping project is proposed where the user identifies the need for a geospatial database and map product depicting dominance type taxonomic units as well as tree canopy cover technical groups. The map unit design process recognizes that these map units are a combination of the map units from examples 2 and 3; therefore, are all unique combinations of the two sets. These relationships are listed in table 3.15. An illustration of map features depicting these map units is provided in figure 3.4.

Table 3.15. Combined Dominance Type and Tree Canopy Cover Classification Map Units

Dominance Type	Tree Canopy Cover	Combined Dominance Type and Tree Canopy Cover
Mapping Units	**Mapping Units**	**Mapping Units**
TREE SP. 1&2	10-29.9% Canopy Cover	TREE SP. 1&2 10-29.9% Canopy Cover
	30-59.9% Canopy Cover	TREE SP. 1&2 30-59.9% Canopy Cover
	60-79.9% Canopy Cover	TREE SP. 1&2 60-79.9% Canopy Cover
	80-100% Canopy Cover	TREE SP. 1&2 80-100% Canopy Cover
TREE SP. 3	10-29.9% Canopy Cover	TREE SP. 3 10-29.9% Canopy Cover
	30-59.9% Canopy Cover	TREE SP. 3 30-59.9% Canopy Cover
	60-79.9% Canopy Cover	TREE SP. 3 60-79.9% Canopy Cover
	80-100% Canopy Cover	TREE SP. 3 80-100% Canopy Cover
SHRUB SP. 1	No Tree Canopy Cover	SHRUB SP. 1 No Tree Canopy Cover
HERBACEOUS SP. 1&2	No Tree Canopy Cover	HERBACEOUS SP. 1&2 No Tree Canopy Cover
NON-VASCULAR SP. 1&2	No Tree Canopy Cover	NON-VASCULAR SP. 1&2 No Tree Canopy Cover
SPARSE VEGETATION	No Tree Canopy Cover	SPARSE VEGETATION No Tree Canopy Cover

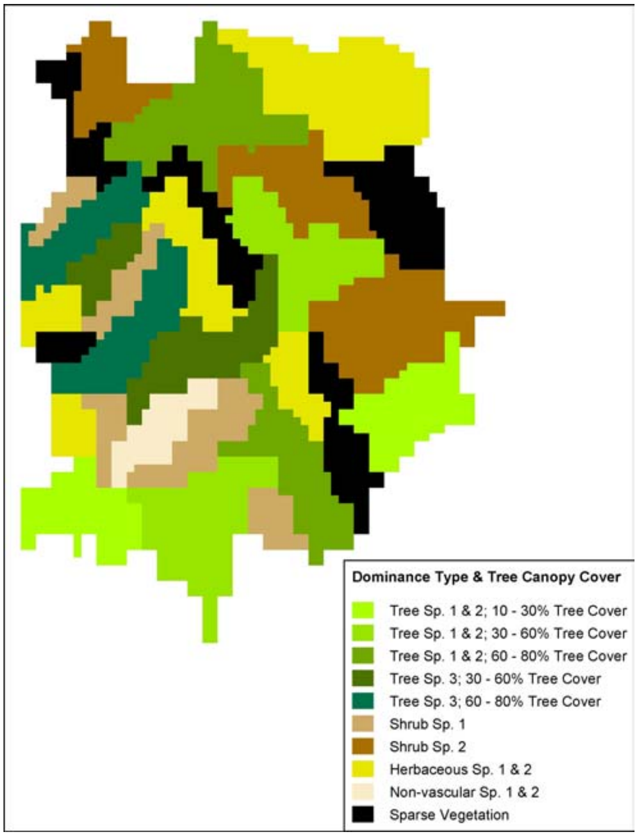

Figure 3.4. Combined Dominance Type and Tree Canopy Cover.

Examples 1 through 4 represent very simple single-purpose mapping projects where the relationships between the taxonomic units and technical groups of the classifications and map units of the map product are fairly direct. In practice, however, most mapping projects are implemented to meet more general purposes. In most cases mapping projects will produce geospatial databases that contain all the map units (physiognomic, floristic, and structural) that are included in this protocol direction for any given level of mapping. This will generally require differentiating and delineating map features based on complex map unit design criteria that incorporate all the taxonomic units and technical groups from all the vegetation classifications being mapped. When the delineation of each map feature is based on all applicable vegetation classifications (physiognomic, floristic, and structural) the resulting geospatial database provides a flexible tool for a wide variety of analysis objectives.

3.24 Map Product Development and Assessment

In this section:
- ***General overview of the mapping process (3.241)***
- ***Steps to producing Mid- and Base-level vegetation maps (3.242,3.243)***
- ***Technical discussion of data sources and mapping methods used in the production of vegetation maps (3.244)***

The information contained in section 3.24 is presented in a format analogous to three tiers of a pyramid. The top tier provides an overview of the general process categories that comprise an entire mapping project. The second tier summarizes the activities performed within each of those processes specifically for Mid- and Basel-level map development. The third and most technical tier presents a number of methodological considerations for performing mapping activities. These considerations are based on existing and former mapping efforts within the agency and are intended to give insight into appropriate data sources and technologies currently available for map development. They are not exhaustive nor the only means by which vegetation mapping can be implemented. Project managers and analysts should conduct a thorough mapping process investigation.

The intent of this section organization is to make this document useful to a broad audience with varying levels of need for understanding the mapping process. Program managers may only need to know a general process outline to understand basic resource requirements; whereas a mapping analyst requires a more technical understanding of the data and technologies applied.

3.241 Vegetation Mapping Overview

Producing a vegetation map to the standards specified in this document is a multidisciplinary activity. Beginning with classification of the vegetation communities described in section 2 through the finalization of a GIS database and associated metadata, a series of processes must be completed utilizing the skills contained within several resource and technical fields. When considered at its most basic level, vegetation map production can be summarized by the following process categories.

- Identify mapping project based on information need
- Identify the mapping system and its relevant components
- Develop project plan
- Assemble the resources necessary to produce a map including people, hardware/software, and data
- Perform the actual mapping tasks
- Conduct an accuracy assessment
- Build GIS database and associated metadata
- Update data on a cyclical basis

Minimum Skill Requirements:

Vegetation Ecologist
Field Forester(s)
GIS Technician
Remote Sensing Specialist/Photogrammetrist

Timeframes to accomplish the processes related to initial map production are dependent on geographic extent, map level, and resource availability. Mapping projects may easily span more than 1 year and represent a significant commitment of resources to be successful. Furthermore, these products should be viewed as ‘living maps’ to be maintained on a regular basis as opposed to one-time investments that will quickly become outdated and have limited value for resource monitoring.

Map product development and assessment are discussed in more detail for mid- and base-level map products. Development of broad- and national-level map products can be accomplished using many of the same methods identified for the mid-level and/or through the aggregation of finer-level maps meeting the specified standards. Stepwise processes for producing mid- and base-level maps are illustrated and summarized in the following sections. A more detailed discussion of underlying principles follows steps for developing each of the map levels.

3.242 Producing a Mid-Level Existing Vegetation Map

Figure 3.5 illustrates the processes necessary to develop a mid-level map product meeting the map standards identified in section 3.22. Processes for mapping additional attributes required at the regional or local level will need to be identified and discussed by the local data stewards. **Appendix 3C includes examples of mid-level mapping protocols in operational use within the agency.**

Steps in Producing a Mid-Level Vegetation Map--The following steps are discussed in the general chronological order they occur, though variation in mapping methods and availability of existing data and resources may alter the progression within a given project.

Step 1: Map Unit Design

- Identify existing floristic classifications for plant associations or dominance types for the area being mapped. Identify plant associations or dominance types that are to be mapped as compositional group(s) or vegetation complex(es) map unit(s).

Step 2: Acquire and prepare the necessary data. Identify and acquire primary and ancillary data appropriate for mid-level map development (Table 3.16). Process the primary data to ensure adequate geospatial registration and data content. Evaluate and process ancillary data to ensure appropriate scale, georegistration, and extent.

- Acquire and process appropriate primary image data to be used for delineation and classification.
    - Radiometric correction
    - Geometric correction
    - Terrain correction
    - Generate derivative data (Normalized Difference Vegetation Index (NDVI), Principal Component Analysis (PCA), texture, *etc.*)
    - Mask imagery to sub-project processing areas within project area extent
- Gather ancillary data, determine utility, and process for project use.
    - Consider the appropriate resolution and/or scale of capture
    - Reproject to desired projection, if necessary
    - Clip/mask to project area extent
    - Generate derivative layers (slope/aspect, hillshade, layer buffers, *etc.*)

Step 3: Delineate Vegetation and Landscape Features. Delineate continuous patches of similar vegetation composition and structure based on primary data source and consistency with the map unit design. Use computer-based systematic methods of generating polygons (image segmentation) or integrate/aggregate from existing base-level maps. Additional information on image segmentation and thematic aggregation is found under the Principles of Map Product Development and Assessment section (3.244).

- Prepare inputs for image segmentation.
    - Layer stack segmentation inputs (image bands, image derivatives, and ancillary data)
- Integrate base-level maps where they exist.
    - Aggregate detailed map units to required level in the classification hierarchy
    - Aggregate below minimum map features to required minimum map feature size, if necessary, using adjacency and similarity logic

Step 4: Assemble and Collect Reference Data Necessary for Mapping and Accuracy Assessment. Gather existing plot data and/or collect new plot and/or photo interpretation data and summary observation data to be used for computer training, model development, interim map assessment, and final accuracy assessment.

- Assemble existing plot data and evaluate for sample intensity and data content to determine utility for development or assessment.
- Collect new plot data and/or photo interpretation data for map development or accuracy assessment.
- Conduct rapid assessments to gather extensive summary data for training, ecological model rule development, and interim map assessments.

Step 5: Assign Attributes to Map Features (polygons). Map each of the standard attributes independently in a hierarchical process, applying appropriate image classification and/or modeling techniques (Table 3.16). Map more general attributes (sub-class) first and subsequently use as stratification for tree specific attributes (dominance type, canopy closure, and size) to increase process efficiency. Field and/or photographically review and correct map units for non-systematic error.

- Map standard attributes.
    - Classify imagery for sub-class and edit results
    - Classify imagery for Anderson 1 land cover types
    - Classify imagery to total vegetation cover
    - Model/classify dominance types within mapped sub-class categories
    - Classify structure within mapped subclass categories
    - Map additional attributes

Table 3.16. Mid-level Mapping Methods

Map Attribute	Appropriate Mapping Methods
Physiognomic Order	Generalized from physiognomic class
Physiognomic Class	Generalized from cover or dominance type
Physiognomic Sub-Class	Supervised/unsupervised image classification
Cover Type (*e.g.*, SRM/SAF)	Spatial modeling based on ecological predictors and existing cover type (augmented with image classification)
Dominance Type	Spatial modeling based on ecological predictors and existing physiognomic class (augmented with image classification)
Total Vegetation Cover	Supervised/unsupervised image classification
Tree Canopy Closure	Supervised/unsupervised image classification Image based modeling Hybrid classification (classification-plot regression)
Tree Diameter	Supervised/unsupervised image classification Hybrid classification (classification-plot regression)
Anderson 1 Class*	Supervised/unsupervised image classification

*Required for polygons with less than 10% total vegetation cover

Step 6: Move Maps Into a Corporate Database Format and Apply Crosswalks to Complete the Database Hierarchy and Link to Other Classification Systems. Combine independently mapped attributes into a corporate database structure (Appendix 3F) and audit/rectify database anomalies. Apply crosswalks to populate upper levels of the hierarchy and additional classification systems identified for local needs.

- Create a single geospatial database containing all mapped attributes.
- Add remaining database elements of the corporate database structure.
- Apply crosswalks to populate upper levels of the hierarchy and additional classification systems.
- Overlay with other Geographic Information Systems (GIS) layers to populate additional attributes.
- Audit the database and spatial layer for sub-standard anomalies, GIS errors, and illogical map attribute combinations.

Step 7: Conduct a Map Accuracy Assessment. Using an independent reference dataset, compare labeled reference data to map labels to generate error matrices for each map attribute/class. Consider generating fuzzy set accuracy assessments in addition to standard error matrices.

- Assemble independent reference dataset.
    - Calculate attribute labels from data
- Compare labeled reference data with map labels for each attribute.

- Evaluate spatial relationships of reference data to map features to determine the validity of individual reference data records for map assessment

- Generate error matrices.
- Analyze error structure relative to the map unit design to identify possible aggregation or other changes to improve accuracy.

Step 8: Finalize FGDC Compliant and Additional Metadata. Populate FGDC metadata template (Appendix 3E). Assemble additional compendium of more detailed source data and methods documentation created during the mapping process. Archive project backup media.

- Populate FGDC-compliant metadata template.
- Compile documentation created during the mapping process.
- Create archive of project data backups and documentation.

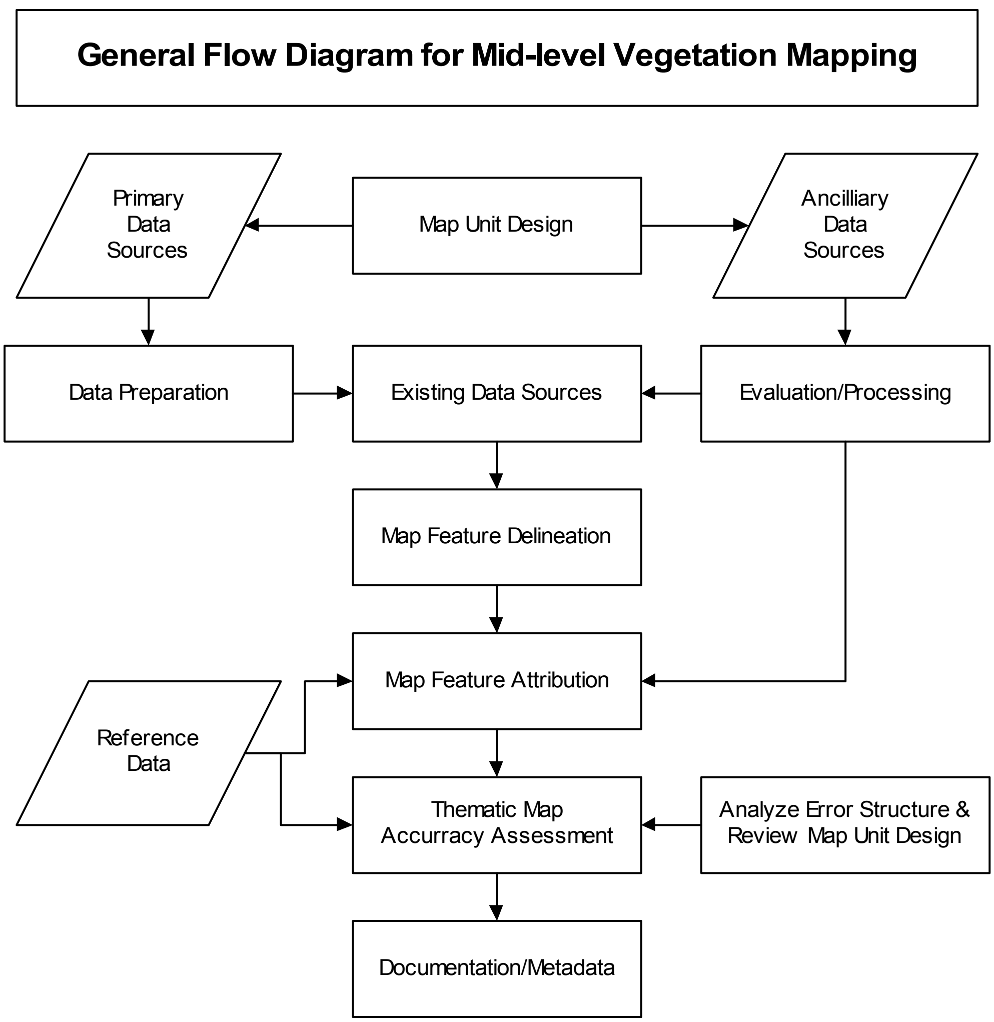

Figure 3.5. Map Product Development and Assessment Mid-Level Vegetation Mapping.

3.243 Producing a Base-Level Map

Figure 3.6 illustrates the processes necessary to develop a base-level map product meeting the map standards identified in section 3.22. Processes for mapping additional attributes required at the regional or local level will need to be identified and discussed by the local data stewards.

Steps in Producing a Base-Level Vegetation Map--The following steps are discussed in the general chronological order they occur, though variation in mapping methods and availability of existing data and resources may alter the progression within a given project.

Step 1: Map Unit Design

Identify appropriate floristic classification of plant associations and alliances within the area to be mapped. Determine which, if any, plant associations will be mapped as compositional group(s) or vegetation complex(es) map unit(s). If formal classifications for part or all of the existing vegetation do not exist, complete vegetation sampling and classification before proceeding with mapping.

Step 2: Acquire and prepare the necessary data. Identify and acquire primary and ancillary data appropriate for base-level map development (Table 3.17). Evaluate and process ancillary data to ensure appropriate scale, georegistration, and extent.

- Acquire primary photo/image data.
  - Appropriate photo scale to identify map attributes?
  - Orthorectify digital data if necessary
- Gather ancillary data, determine utility, and process for project use.
  - Consider appropriate resolution and/or scale of capture
  - Reproject to desired projection system if necessary
  - Clip/mask to project area extent (including buffer)
  - Generate derivative layers (slope/aspect, hillshade, layer buffers, *etc.*)

Step 3: Assemble and Collect Reference Data Necessary for Mapping and Accuracy Assessment. Gather existing plot data and/or collect new plot and summary observation data to be used for interpreter calibration, model development, interim map assessment, and final accuracy assessment.

- Assemble existing plot data and evaluate for sample intensity and data content to determine utility for development or assessment.
- Collect new plot data for map development or accuracy assessment.
- Conduct rapid assessments to gather extensive summary data for ecological model rule development and interim map assessments.

Step 4: Delineate Vegetation and Landscape Features. Delineate continuous patches of similar vegetation composition and structure based on primary data source. Delineations are determined through photography and/or image interpretation and registered to a digital image base. Feature delineation and attribution can occur simultaneously for map attributes that are readily interpreted on large-scale photography.

- Calibrate interpretation analyst based on reference data and mensurational guides that illustrate crown densities and diameters at various photo scales.

- Delineate vegetation stands or patches containing uniform or evenly distributed vegetation structure and top layer species composition.
  - Digitize delineations over a digital image base
- Adjust delineations for species composition (if necessary) based on field observations.

Step 5: Assign Attributes to Map Features (polygons). Map each of the standard attributes that can reliably be interpreted from stereoscopic photography and associated high-resolution imagery (Table 3.17). Attributes not reliably mapped from image/photo interpretation should be mapped based on field observation.

- Map standard attributes.
  - Interpret photography/ imagery for sub-class and label polygons
  - Interpret photography/ imagery for tree canopy closure
  - Interpret photography/ imagery for tree diameter class
  - Interpret photography/ imagery for Anderson 1 land cover types and label polygons
  - Interpret photography/ imagery for total vegetation cover
  - Label polygons with vegetation alliances based on
    - modeling, photograph/image interpretation, and field observation
- Map additional attributes.
-

Table 3.17. Base Level Mapping Methods

Map Attribute	**Appropriate Mapping Methods**
Physiognomic Order	Generalized from Physiognomic Class
Physiognomic Class	Generalized from Plant Alliances
Physiognomic Sub-Class	Photo/image interpretation with field observations
Cover Type	Generalized from Plant Alliances
Dominance Type	Generalized from Plant Alliances
Alliances	Spatial modeling based on ecological predictors (*e.g.*, topography, climate, geology) and existing physiognomic type (augmented with photo/image interpretation and field observation)
Associations	Field observation
Total Vegetation Cover	Photo/image interpretation with field observations
Tree Canopy Closure	Photo/image interpretation with field observations
Tree Diameter	Photo/image interpretation with field observations
Anderson 1 Class	Photo/image interpretation with field observations

Step 6: Move Maps Into a Corporate Database Format and Apply Crosswalks to Complete the Database Hierarchy and Link to Other Classification Systems. Combine mapped attributes in a corporate database structure (Appendix 3F) and audit/rectify database anomalies. Apply crosswalks to populate upper levels of the hierarchy and additional classification systems identified for local needs.

- Create a single geospatial layer containing all mapped attributes as separate database elements.
- Add remaining database elements of the corporate database structure.
- Apply crosswalks to populate upper levels of the hierarchy and additional classification systems.
- Overlay with other GIS layers to populate additional attributes not related to vegetation.
- Audit the database and spatial layer for sub-standard anomalies, GIS errors, and illogical map class combinations between attributes.

Step 7: Conduct a Map Accuracy Assessment. Using an independent reference dataset, compare labeled reference data to map labels to generate error matrices for each map attribute/class. Consider generating fuzzy set accuracy assessments in addition to standard error matrices.

- Assemble independent reference dataset.
    - Calculate attribute labels from data
- Compare labeled reference data with map labels for each attribute.
    - Evaluate spatial relationship of reference data to map features to determine the validity of individual reference data records for map assessment
- Generate error matrices.

Step 8: Finalize FGDC Compliant and Additional Metadata. Populate FGDC metadata template (Appendix 3E). Assemble additional compendium of more detailed source data and methods documentation created during the mapping process. Archive project backup media.

- Populate FGDC-compliant metadata template.
- Compile documentation created during the mapping process.
- Create archive of project data backups and documentation.

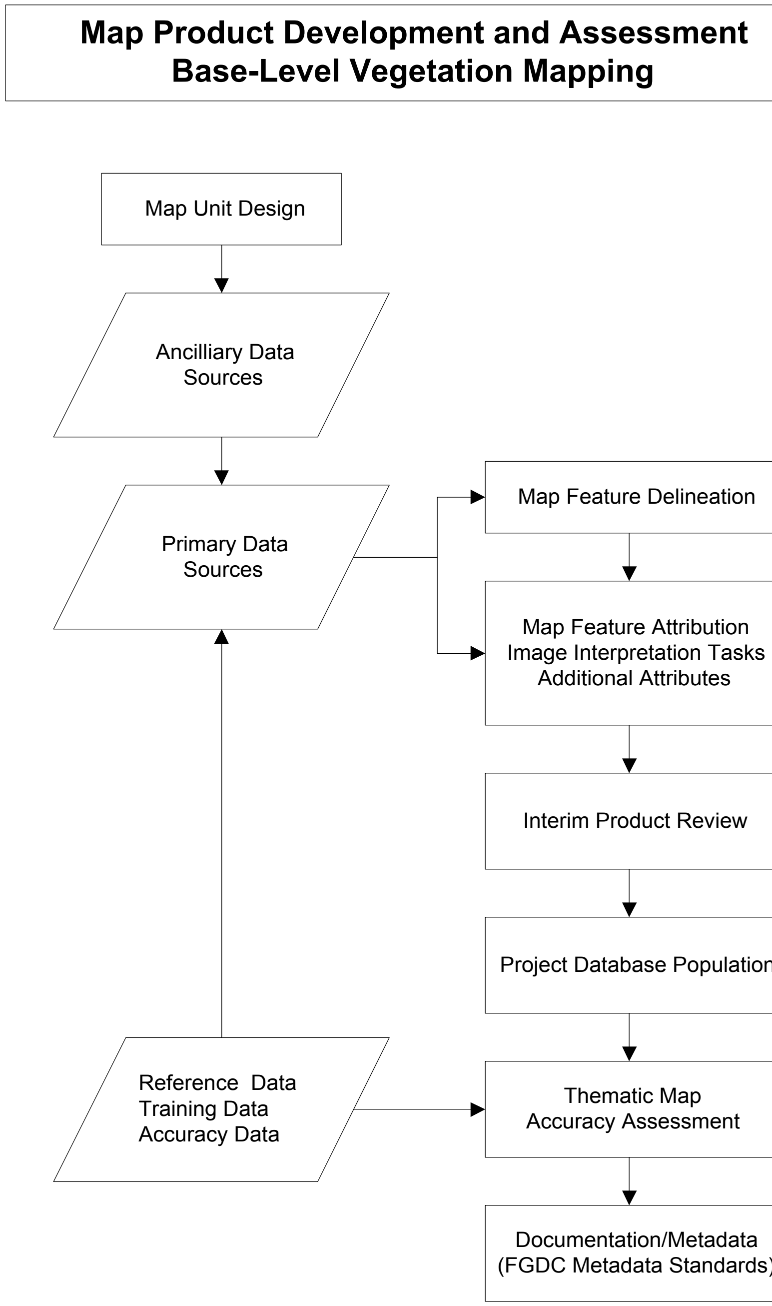

Figure 3.6. Map Product Development and Assessment Base-Level Vegetation Mapping.

3.244 Principles of Map Product Development and Assessment

Existing Information Sources

Vegetation mapping across the range of map levels outlined in this protocol is primarily accomplished through the use of remotely sensed image data. These data can be acquired from either airborne or space borne platforms and can be either in photographic or digital form. A brief discussion of remote sensing systems, common remote sensing data sources, and the methods used to extract thematic information will provide insights into the similarities and differences of vegetation mapping approaches based on either photographic or digital data. "Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by device that is not in contact with the object, area, or phenomenon under investigation" (Lillesand and Kiefer 1987). The following remote sensing data sources are the products of complex systems. A thorough discussion of these systems and the energy-matter interactions that affect the basic nature of these data is far beyond the scope of this protocol. A brief overview, however, is necessary for an understanding of the differences in how information is extracted from these data and how this information relates to the attributes and standards for vegetation maps. For detailed descriptions refer to Campbell (1987), Lillesand and Kiefer (1987) and Jensen (1996).

In their simplest form, the complex matter/energy interactions involved in passive electromagnetic remote sensing are described by three basic processes. Energy from the sun propagates through the atmosphere, interacts with earth surface features, and retransmits through the atmosphere where it becomes available to a remote sensing device. The atmosphere has a substantial effect on the intensity and spectral composition of energy available to remote sensing system. These effects result primarily from atmospheric scattering and absorption. Space-borne sensors are more affected by the atmosphere than the airborne sensors since their energy source passes through the full thickness of the atmosphere twice. Energy incident on any earth surface feature will have various portions reflected, absorbed, and/or transmitted. The proportions of energy that are reflected, absorbed, and/or transmitted vary for different surface features and provide the basis for distinguishing different types of features in an image. Because of the nature of the matter/energy interactions, two features may be indistinguishable in one portion of the electromagnetic spectrum and easily distinguished in another. Many remote sensing devices are designed to utilize this variable response and collect data in several specific regions of the electromagnetic spectrum. A number of multi-spectral image data sources are included in our discussion of potential remote sensing data sources. The other data sources collect data (both color and panchromatic) only in the visible portion of electromagnetic spectrum.

All of the primary remote sensing data sources described here are passive sensors of electromagnetic energy; that is, they all rely on the sun as their source of energy and sense/record data in various portions of the electromagnetic spectrum. These data are digitally recorded in the form of pixels and photographically recorded on crystals or grains of silver halide. A pixel is defined as "a two-dimensional picture element that is the smallest non-divisional element of a digital image". For the purposes of describing the ground resolution of these remote sensing data and discussing the extraction of information, a pixel and a grain of silver halide are reasonably analogous. They both represent the smallest non-divisible element and an integrated signal of some area on the ground.

Development of map products at all levels will depend on the acquisition of both primary and ancillary data sources. Primary data sources are those from which a map is directly derived; whereas, ancillary data sources are used to support development and verification of the map.

Primary Data--Primary data sources are most often continuous data that depict an uninterpreted image of surface condition at a moment in time. A number of primary data sources are logically used for map feature delineation and population. These include satellite based multi-spectral and panchromatic imagery, as well as true color, infrared, and panchromatic digital and hardcopy aerial photography.

Table 3.18 lists commonly available examples of satellite borne sensor data that can be used as a primary image data source. Table 3.19 lists minimum photographic scales recommended for detecting and measuring various vegetation characteristics commonly mapped. Other non-continuous remotely sensed data are available (*e.g.*, lidar (light detection and ranging), but are difficult to apply as a primary source for the development of continuous vegetation information, though they may be effectively used in conjunction with continuous data sources.

When selecting an appropriate data source(s), there are some basic principles to consider that relate the grain of data to the size and shape of the vegetation/landscape elements that constitute the pattern of interest. When the pattern of interest is smaller than the grain of the data, the pattern cannot be detected. When the pattern of interest is much larger than the grain of the data, that pattern can be well represented, provided it can be recognized in those data. This is particularly true when the pattern is composed of spectrally homogenous units organized in regular shapes (shape index approaching 1:1 and/or a fractal dimension approaching 1) (Nellis and Briggs 1989, Turner *et al.* 1989, Cullinan and Thomas 1992, Simmons *et al.* 1992, and Ryherd and Woodcock 1996). For example, a minimum map unit of 5 acres represented by approximately 22 TM pixels, 75 SPOT HRV pixels, and 20000 digital orthophoto pixels, that is essentially homogeneous would be detectable and reasonably well characterized by any of these remote sensing data sources.

As the grain of the data interacts with grain of the vegetation pattern, it creates a problem referred to as boundary pixels. Boundary pixels are those pixels that are not completely filled by one homogenous class of scene object, in this case vegetation. If the area on the ground is relatively uniform then the integrated signal and the resulting digital number are reasonable representations of the area. The problem is created by pixels that represent an area that contains the boundary of two or more features that differ in brightness. The integrated signal of this area becomes an average of the two conditions and may not represent either condition well. If a given map unit is irregular in shape (high edge: interior ratio; shape index much greater than 1:1 and/or a fractal dimension much greater than 1), the proportions of boundary pixels increase relative to non-boundary pixels. A similar condition develops when the pixels comprising an object are not spectrally homogenous. This pattern of heterogeneity results in difficulty segmenting the image into regions (Ryherd and Woodcock 1996).

Selection of primary data sources for map production must be based on the ability of the data to delineate and identify the standard and any supplemental map units. As an example, the use of a 1 kilometer ground resolution satellite image will not allow for the delineation of map units that meet the minimum map feature standard defined for mid-level maps. There are a variety of satellite remote sensing data sources available with highly variable spatial, temporal, and spectral characteristics. Similarly, there are a wide variety of aerial photography data sources available that also vary in their spatial, temporal, and spectral characteristics. It should also be considered that a single primary data source might not adequately be used for the delineation and complete population of all map units. The map producer may need several primary data sources to develop a complete map product. Subsequent factors determining selection of primary data sources will include data availability, quality, and cost. Other considerations should include currency and temporal coincidence of image data.

Data Preparation—Prepare digital imagery for processing through the proper registration and correction of raw data, with the objective to increase both the accuracy and the interpretability of the image prior to image classification. A few important image-preprocessing steps follow:

1. Radiometric correction accounts for variations in the image resulting from sensor anomalies or environmental conditions (such as haze) so that image values represent as closely as possible the true reflectance of land cover features. This step is optional and depends on the severity of the image defects and/or the project's need to show true reflectance values.

2. Geometric correction reorients the image to compensate for the Earth's rotation and for variation in the position and attitude of the satellite. This process may also include positioning or warping an image into a map projection system so that accurate measurements can be made. This step is necessary if the resulting classification products are used in GIS with other georeferenced information layers.

3. Terrain correction adjusts the image for the relief distortion with the help of digital elevation data. Terrain correction is recommended if precise location is required and the study area has relief differences greater than 500 feet.

Table 3.18. Available Digital Image Data Types

Data Type	Coverage (swath width)	Spatial Resolution (meters)	Spectral Resolution [1]	Temporal Resolution (days)	Appropriate Map Level
Landsat MSS	185 km	82	G,R, NIR	N/A	Broad, National
Landsat TM 5, 7	185 km	6 at 30 1 at 60 1 at 15 (Landsat 7 only)	B, G, R, NIR, MIR, TIR	16	Mid, Broad, National
Spot 2	60 km	3 at 20 1 at 10	G, R, NIR	Pointable (less than 5)	Mid, Broad
Spot 4	60 km	4 at 20 1 at 10	G, R, NIR, MIR	Pointable (less than 5)	Mid, Broad
Spot 5	60 km	4 at 10, 1 at 5, 1 at 2.5	B, G, R, NIR MIR	Less than 5	Base, Mid
IRS-1B (LISS 1) (LISS 2)	145 km 74 km	4 at 72.5 4 at 36.25	B, G, R, NIR	22	Broad, National
ERS-1,2 (AMI) (ATSR)	100 km	1 at 26 (Radar) 4 at 1000	Far Infrared B, G, R, NIR	35	Broad, National
RESURS-01-3	600 km	4 at 160 1 at 700	B, G, R, MIR, T IR	21	Broad, National
NOAA (AVHRR)	2700 km	5 at 1100	G, R, M IR Thermal	Daily	National
IRS-P4 (OCM)	1420 km	8 at 360	MIR	2	National
IKONOS	11 km	4 at 4 1 at 1	B, G, R, NIR	1 –3	Base, Mid
IRS-1C, D	142 km 70 km 70 km	3 at 23 1 at 70 1 at 5.8	G, R, NIR, SWIR	24	Base, Mid, Broad
RADARSAT	500 km	1 at 9-100 (Radar)	Far Infrared	3	Mid, Broad, National
CBERS-1(CCD) (WFI) (IRMSS)	113 km 120 km 900 km	5 at 20 2 at 260 3 at 80, 1 at 160	B, G, R, NIR, MIR, Thermal	26	Mid, Broad, National
TERRA(MODIS) (MISR) (ASTER)	2330 km 360 km 60 km	2 at 250, 5 at 500, 29 at 1000 4 at 250 3 at 15, 6 at 30, 5 at 90	B, G, R NIR, MIR, Thermal B, G, R, NIR SWIR, VNIR, Thermal	Daily	Mid, Broad, National
OrbView –2	2800 km	8 at 1130	6 visible, 2 NIR	Daily	National
Orb View -3	8 km	4 at 4, 1 at 1	B, G, R, NIR	Less than 3	Base, Mid
Quickbird 2	17 km	4 at 2.5, 1 at .65	B, G, R, NIR	1-4	Base, Mid
EO-1 (ALI) (Hyperion) (LAC)	37 km 7.6 km	1 at 10 9 at 20 220 at 30 256 at 250	B, G, R, NIR, MIR Hyperspectral –visible to MIR Hyper – MIR to SWIR	7	Mid, Broad, National
EROS-B1	12.7 km	1 at .82	Panchromatic	Daily	Base
Aqua (Modis) (AMSR)	2330 km	2 at 250, 5 at 500, 29 at 1000 1 at 5	B, G, R, NIR, MIR, Thermal, Far infrared	<4	National
SeaWiFS	1502 km	8 at 1100	B, G, R, NIR, MIR, Thermal	1	National

[1] B=blue, G=green, R=red, NIR=near infrared, MIR=mid infrared, TIR=thermal infrared, SWIR=short wave infrared , VNIR=visible near infrared/short wave

Table 3.19. Photographic Scales and Resolution Necessary for Vegetation Mapping

Data Requirements (Map Units)	Ground Resolution (m)	Minimum Scale (IR/CIR2[2] Detection	Measurement	Minimum Scale (BW/Color)[3] Detection	Measurement	Appropriate Common Scale (CIR/IR)	(BW/Color)
Vegetated Cover							
Tree Stands	3	1:184,000	1:92,000	1:320,000	1:160,000	1:60,000	1:40,000
Tree Species	0.1	1:3,200	1:1,600	1:5,000	1:2,500	Special Project	
Tree Stand Height Class	0.3	1:12,500	1:6,400	1:20,000	1:9,600	1:12,000	1:12,000/1:16,000
Tree Stand Mean Diameter	0.3	1:12,500	1:6,400	1:20,000	1:9,600	1:12,000	1:12,000/1:16,000
Tree Stand Crown Closure	0.3	1:12,500	1:6,400	1:20,000	1:9,600	1:12,000	1:12,000/1:16,000
Shrub Stands	3	1:184,000	1:92,000	1:320,000	1:160,000	1:60,000	1:40,000
Shrub Species	0.3	1:12,500	1:6,400	1:20,000	1:9,600	1:12,000	1:12,000/1:16,000
Shrub Stand Height Class	0.3	1:12,500	1:6,400	1:20,000	1:9,600	1:12,000	1:12,000/1:16,000
Shrub Stand Form Class	0.3	1:12,500	1:6,400	1:20,000	1:9,600	1:12,000	1:12,000/1:16,000
Forb Stands	3	1:184,000	1:92,000	1:320,000	1:160,000	1:60,000	1:40,000
Grass Stands	3	1:184,000	1:92,000	1:320,000	1:160,000	1:60,000	1:40,000
Non-Vegetated Cover							
Rock	3	1:184,000	1:92,000	1:320,000	1:160,000	1:60,000	1:40,000
Barren	3	1:184,000	1:92,000	1:320,000	1:160,000	1:60,000	1:40,000
Water	3	1:184,000	1:92,000	1:320,000	1:160,000	1:60,000	1:40,000
Land Use	3	1:184,000	1:92,000	1:320,000	1:160,000	1:60,000	1:40,000

Ancillary Data--Other data sources are available and may be used to support map unit delineation and map unit population. These include vertical aerial photography, videography, digital orthophoto quads, DEM, historical vegetation data and maps, other ecologically related data and maps (*e.g.*, soils and hydrography), and disturbance and land use information (*e.g.*, fire history, silvicultural treatments, urban succession). Consideration must be given to the scale of capture associated with an ancillary data source relative to the desired level of detail in the map product and scale of the source data. As an example, it may not be appropriate to rely on a 1:100000-scale hydrographic layer to aid mapping riparian related vegetation types at the mid level. Conversely, at the mid level, a 1:24000 DEM can greatly enhance the ability to map the distribution of vegetation types constrained by elevation. Consideration must also be given to the use of multiple ancillary datasets or map layers that vary considerably in scale. Both spatial and thematic accuracy may vary considerably between sets of information. Spatial co-registration may be necessary to appropriately use two or more independent layers as inputs into the same process.

Map Feature Delineation

Criteria are established for use in spatially differentiating map features between map units. Those criteria describe structural, floristic, and physiognomic characteristics of the vegetation to be mapped, as well as non-vegetated landscape elements. Within the context of this protocol, the delineation of map features depicting the vegetation configuration across the landscape representing elements of vegetation pattern can be synonymous with either landscape patch delineation or stand delineation. The term "patch", as defined in a glossary of common terms included in *Land Mosaics: The Ecology of Landscapes and Regions* (Forman 1995), is "a relatively homogenous nonlinear area that differs from its surroundings". This definition is consistent with other

[2] IR=infrared, CIR=color infrared
[3] BW=panchromatic

common reference texts including Picket and White (1985) and Forman and Godron (1986). It is also consistent with the common use of the term in the landscape ecology literature (Hartgerink and Buzzaz 1984, Scheiner 1992). The term patch can specifically describe forested patches, non-forest vegetation patches, rock/barren patches, or water patches. In contrast, the term “stand” has long been used to refer to the basic unit of forest management (Toumey 1937). It also has been used as the basic unit of mapping and inventory (Graves 1913). A “stand” is defined as "a community, particularly of trees, possessing sufficient uniformity as regards composition, age, spatial arrangement, or condition, to be distinguishable from adjacent communities, so forming a silvicultural or management entity". This definition of a stand from the Society of American Forester's *Terminology of Forest Science, Technology, Practice, and Products* (Ford-Robertson 1971) is consistent with definitions from a variety of reference texts including Toumey (1937), Smith (1986), and Oliver and Larson (1990), as well as *A Dictionary of Ecology, Evolution, and Systematics* (Lincoln *et al.* 1982) and the definition provided in the USDA Forest Service Timber Management Handbook (FSH 2709). Historically, most vegetation mapping completed by the agency has been conducted through delineation of forest stands. In the context of this protocol, the terms “patch” and “stand” may be synonymous depending on the degree that management considerations are incorporated into stand delineations along with compositional and structural characteristics. It is important to recognize, however, that many past stand delineations contain multiple vegetation conditions and map units, thus would be multiple map features in any new mapping effort.

Guidelines for Map Feature Delineation

Image Interpretation--Image interpretation is the systematic examination of image data. This frequently involves other supporting materials, such as maps and field observations (Lillesand and Kiefer 2000). “The basis for delineation of map units is normally discontinuities in texture (reflecting life form composition, stocking, tree crown size differences, and/or apparent tree height (Stage and Alley 1973).” If map feature delineation is completed with aerial photography, the process normally uses stereoscopic, vertical aerial photography. This process involves transferring the photo delineations to a base map and converting to a digital form. An alternative image interpretation technique involves interpretation of stereoscopic pair aerial photography in conjunction with interpretation of high-resolution digital imagery. Simultaneous on-screen delineation has the benefit of resulting in an immediate digital product. Photographic and digital image interpretations without the use of stereoscopic photographic pairs suffer from the constraint of a one-dimensional depiction of vegetation cover. Image interpretation is the most intuitive form of map feature delineation, but is also the most subjective and least cost effective.

Image Segmentation--As stated in Ryerd and Woodcock (1996), “Image segmentation is the process of dividing digital images into spatially cohesive units, or regions. These regions represent discrete objects or areas in the image”. If map feature delineation is completed with digital imagery, the process normally uses data from space-borne remote sensing platforms. The basis for delineation of map units is usually the segmentation and merging of raster data based on spectral characteristics and spatial arrangement. This segmentation and merging process is influenced by the variance structure of the image data and provides the modeling units that reflect life form composition, stocking, tree crown size differences, and other vegetation/land cover characteristics. Because these are geospatial data, the delineations do not require transfer to a base map. Image segmentation is the most objective and typically lowest cost approach to map feature delineation, but is the farthest removed from human intuition. Image segmentation is most often used to develop mid- and broad-level map products as it offers substantial spatial detail in a consistent and repeatable fashion over large areas.

Thematic Aggregation--Thematic aggregation is the process of combining spatially distinct map features based on their categorical similarity and spatial arrangement. Thematic aggregation is not a stand-alone approach to feature delineation. However, feature delineations generated at lower levels in the hierarchy may preclude the necessity to directly delineate features at higher levels. If map features are derived through aggregation routines, a clear set of aggregation parameters or rules need to be developed. Aggregation parameters must consider the thematic relationship of potentially merged features (*e.g.*, the aggregation of two similar tree types is more desirable than the aggregation of a tree type and a non-vegetated class). Aggregation parameters are defined by thematic similarity and composition of the aggregated feature and are ideally based on a hierarchical classification scheme.

Aggregation as a means of feature delineation is most commonly applied at the coarsest map levels and, if applied at the mid level, should only supplement more direct delineation techniques. Base-level mapping presumes no finer continuous map product exists and aggregation is not an applicable technique.

Table 3.20. Data Sources and Methods for Map Feature Delineation

Map Level	Min. Map Feature Standard (acres)	Data Source(s)	Delineation Method(s)
National	500	medium to coarse resolution multi-spectral or panchromatic imagery (30m-1km), existing broad or mid-level vegetation maps	data aggregation of broad- or mid-level maps, image segmentation
Broad	20	medium resolution multi-spectral or panchromatic imagery (10m-30m), small scale photography (1:40000-1:80000), existing mid- and base-level maps	data aggregation of mid- or base-level maps, image segmentation, image interpretation
Mid	5	fine to medium resolution multi-spectral or panchromatic imagery (1m-30m), mid-scale photography (1:15840-1:40000), existing base-level maps	image segmentation, image interpretation, data aggregation of base-level maps
Base	5	fine resolution multi-spectral or panchromatic imagery (<5m), large scale photography (1:5000-1:15840)	image interpretation

Aggregation of map features that have an areal extent below the minimum map feature standard, should be accomplished using logic that aggregates based on thematic similarity of map unit attribute(s) as apposed to aggregating based on longest shared perimeter (*e.g.,* opening the longest shared arc). The following tables are simple guidelines for developing a merge routine that will minimize the variability of a map unit within a map feature associated with merging adjacent features.

Table 3.21A. Aggregation Logic

If Physiognomic Order is different than any adjacent map feature:

Adjacent Feature	Below Min. Feature - Tree Order	Below Min. Feature - Shrub Order	Below Min. Feature - Herbaceous Order	Below Min. Feature - No Dominate	Below Min. Feature - Non-Vegetated
Tree Order	different	merge second	merge fourth	merge fourth	merge fourth
Shrub Order	merge first	different	merge third	merge third	merge third
Herbaceous Order	merge second	merge first	different	merge second	merge second
No Dominate - Sparse	merge third	merge third	merge first	different	merge first
Non-Vegetated	merge fourth	merge fourth	merge second	merge first	different

Table 3.21B. Aggregation Logic

If Physiognomic Order is the same as at least one adjacent map feature:

Map Unit Attribute	Priority	Herbaceous Order	Herbaceous Order	Herbaceous Order
Floristics	1	different - merge	na	na
Physiognomic Subclass	2	same	different - merge	na
Physiognomic Class	3	same	same	different - merge

Map Unit Attribute	Priority	Shrub Order	Shrub Order	Shrub Order	Shrub Order
Shrub Cover	1	different - merge	na	na	na
Floristics	2	same	different - merge	na	na
Physiognomic Subclass	3	same	same	different - merge	na
Physiognomic Class	4	same	same	same	different - merge

Map Unit Attribute	Priority	Tree Order	Tree Order	Tree Order	Tree Order	Tree Order
Tree Cover	1	different - merge	na	na	na	na
Tree Size	2	same	different - merge	na	na	na
Floristics	3	same	same	different - merge	na	na
Physiognomic Subclass	4	same	same	same	different - merge	na
Physiognomic Class	5	same	same	same	same	different - merge

Floristics in tables 3.21A and 3.21B refer to map units based on classification systems of cover type, dominance type, or plant alliances.

Map Feature Attribution

The process of mapping vegetation characteristics and assigning map unit labels or category to each map feature is referred to as map feature attribution. At a minimum, each map feature is attributed with a category from each of the standard map units defined in section 3.22. The map feature attribution process is generally applied in two steps: 1) classifying the landscape in terms of the map units, and 2) labeling map features (polygons) with map attributes. Depending on the mapping methodology, these two steps can be applied simultaneously or successively. Image interpretation usually accomplishes these two steps simultaneously; while image classification often separates these two steps into two distinct processes.

The methods used to map vegetation characteristics may vary by map attribute and level. As with the selection of image data sources, not all possible methods are appropriate across the range of map levels. The following guidelines provide direction for appropriate methods used to map the standard attributes at the mid- and base- levels. Specific examples of mapping methodologies that have been successfully used in the agency can be found in the appendices. The standards defined in section 3.22 and the guidelines provided in conjunction with the associated examples, should enable the development of vegetation mapping work plan and/or development of mapping contract specifications.

As previously discussed, vegetation mapping across the range of map levels outlined in this protocol is primarily accomplished through the use of remotely sensed image data. Map feature attribution is, therefore, a remote sensing classification or interpretation process. The methods discussed here apply to the base- and mid-level map products with the assumption that broad- and national-level maps are generalizations of the mid-level map features and will be generated by aggregating those data.

Many common textbooks on digital image processing of satellite remote sensing data and interpretation of aerial photography discuss the process of extracting information from remotely sensed data, or "decoding" information from raw uninterpreted images. Image classification of satellite remote sensing imagery and interpretation of aerial photography are analogous processes. Both of these processes are data models intended to represent complex natural systems. On the most basic level, the image interpretation and classification processes are essentially the same. On this level, both processes group similar objects and then label them with some form of thematic information. Beyond this most basic level, however, these processes have some fundamental differences related to the basic remote sensing data, the analytical logic and methods, as well as the "tools" used to extract the information.

The following sections briefly outline and describe the image interpretation process (not limited to aerial photography interpretation) and the satellite image classification process. These two processes are discussed in combination to illustrate their relationships. This description of the tasks involved in these processes is very abbreviated to remain within the scope of this protocol. These descriptions generally follow Avery (1977), Estes *et al.* (1983), Simonett *et al.* (1983), Campbell (1987), Lillesand and Kiefer (1987), Jensen (1996), and Lachowski *et al.* (1995 and 1996). There are many minor variations on the basic tasks described here, both in other textbooks and in the remote sensing literature. Similarly, the elements of image interpretation presented here are also fairly common in the aerial photography interpretation literature and most of these elements have analogs in the classification of satellite imagery. Literature suggesting applications of the digital analogs of these elements is referenced with the most applicable element.

Elements of Image Interpretation--The following section briefly outlines and describes the elements of image interpretation. These elements, with some variation, are fairly common in the aerial photography interpretation literature (Avery 1977, Estes *et al.* 1983, Simonett *et al.* 1983, Campbell 1987, Lillesand and Kiefer 1987, and Jensen 1996) and most of these elements have analogs in the classification of satellite imagery. Literature suggesting applications of the digital analogs of these elements is referenced with the most applicable element. This listing is not an exhaustive review of the remote sensing classification and related topic literature. It simply represents some literature considered generally applicable to this protocol.

Image tone denotes the lightness or darkness and/or color of a region within an image. Values for each cell in each band in multi-spectral data would be analogous. See remote sensing literature that relates primarily to this element.[4]

Image texture refers to the apparent roughness and smoothness of an image region created by the frequency of tonal change on the image. Usually texture is caused by the pattern of highlighted and shadowed areas as an irregular surface is illuminated from an oblique angle. Tonal change among groups of pixels would be analogous. See remote sensing literature that relates primarily to this element.[5]

Shadow is especially an important clue in the interpretation of objects. Shadows of buildings, trees, *etc.*, reveal characteristics that would not be obvious from the overhead view alone. Edges, such as forest boundaries, often have characteristic shadows.

Pattern refers to the arrangement of individual objects into distinctive, recurring forms that permit recognition. The distinctive pattern of an orchard, baseball diamond, or drive-in theater makes them identifiable. A recurring pattern between adjacent pixels can be used as one of the features of a contextual classification of digital imagery. See remote sensing literature that relates primarily to this element.[6]

Association specifies characteristic occurrence of certain objects or features, usually without the strict spatial arrangement implied by pattern. The identification of a baseball diamond, for instance, is often associated with a school or park.

Shape refers to the general form, configuration, or outline of individual objects. For example, lakes, rivers, timber harvest units, and center pivot irrigation fields

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[4] Hixson *et al.* 1980, Strahler 1980, Crapper and Hynson 1983, Crist and Kauth 1986, Shasby and Carneggie 1986, Fung and LeDrew 1987, Chavez and Bowell 1988, Chuvieco and Congalton 1988, Leprieur and Durand 1988, Chavez and Kwarteng 1989, De Cola 1989, Hepner *et al.* 1990, Mausel *et al.* 1990, Wang 1990, Cetin and Levendowski 1991, Cohen 1991, Loveland *et al.* 1991, Foody *et al.* 1992, Brown *et al.* 1993, Nemani *et al.* 1993, Samson 1993, Bauer *et al.* 1994, Collins and Woodcock 1994, Coppin and Bauer 1994, Green et al. 1994, Woodcock et al.1994, Collins and Woodcock 1996, Foody 1996, Gao 1996, Lambin and Ehrlich 1996, White *et al.* 1996, Fassnacht *et al.* 1997, Johnston *et al.* 1997, White *et al.* 1997; Asner *et al.* 1998, Carlotto 1998, Chalifoux *et al.* 1998, Cohen *et al.* 1998, Deppe 1998, Mickelson *et al.* 1998, and Todd and Hoffer 1998.

[5] Haralick *et al.* 1973, Vilnrotter *et al.* 1986, Nellis and Briggs 1989, Franklin and Peddle 1990, Marceau *et al.* 1990, Peddle and Franklin 1991, Cohen and Spies 1992, Gong *et al.* 1992, Kushwaha *et al.* 1994, Cohen *et al.* 1995, Dikshit and Roy 1996, Hay *et al.* 1996, Ricotta *et al.* 1996, Ryherd and Woodcock 1996, Wulder *et al.* 1996, Jakubauskas 1997, Wulder *et al.* 1998, Bian and Butler 1999, and Emerson *et al.* 1999.

[6] Cross *et al.* 1988, Moller-Jensen 1990, Gong and Howarth 1992, Woodcock and Harward 1992, Kontoes and Rokos 1996, Shandley *et al.* 1996, Sharma and Sarkar 1998.

all have shapes that can provide clear identification.

Size of an object or feature is considered in relation to other objects on the image and in relation to the photo scale.

Site refers to the topographic position, geographic location, or other biophysical environment factors; *e.g.*, streams and rivers are positioned in valley floors and lookout towers are positioned on mountaintops or ridges. Other features occur only in some geographic locations, such as palm trees. This element could also refer to site characteristics such as potential vegetation setting. See remote sensing literature that relates primarily to this element.[7]

Image Interpretation for Base-Level Mapping--It is expected that high-resolution image interpretation completed by skilled interpreters will comprise the basis for base-level vegetation maps. It is also expected that extensive field data and validation will be incorporated into this process. Depending on the thematic detail in the classification scheme for any given map product (*i.e.*, plant associations vs. alliances), the image interpretation task will involve various amounts of field validation sampling. This fieldwork could range from simple "ground-truth" reconnaissance to a formal two-stage sample design to a complete field-data based attribution of map delineations. Appendix 3B includes example of a structured aerial photo interpretation data gathering protocol in operational use within the agency.

Image/Photo Interpretation Tasks:

- Classification assigns objects, features, or areas to categories based on their appearance on the imagery.
- Enumeration refers to listing and counting discrete items visible on an image. Enumeration reports the numbers of classified items present within a defined area.
- Mensuration focuses on two kinds of measurement. The first measurement of distance, height, volumes, and areas is photogrammetry. The second measurement of image brightness is the photometry.
- Delineation outlines photomorphic patches or regions as they are observed on remotely sensed images. These areal units are characterized by specific tones and textures to identify edges or boundaries between separate areas.

Campbell (1987) describes five general image interpretation strategies that are likely to be incorporated into the base-level vegetation mapping process.

1. The use of **field observations** to identify features on the imagery. This strategy has been employed to greater or lesser degrees by nearly all photo interpreters and provides reference or training data for most supervised and unsupervised classifications of satellite imagery.
2. **Direct recognition**, the application of the interpreter's accumulated experience, skill, and judgment to map features recorded on an image. An example

[7] Hutchinson 1982, Cibula and Nyquist 1987, Janssen *et al.* 1990, Bolstad and Lillesand 1992, Franklin and Wilson 1992, Gong 1996, Lakowski *et al.* 1997, Stoms *et al.* 1998.

would be the recognition of a golf course or baseball diamond on aerial photographs.

3. Interpretation by **inference**, the use of the visible distribution for a distribution that is not visible on the image. An example is interpretation of soil patterns, inferred from vegetation and topography, from aerial photographs. This strategy constitutes the vast majority of classifications of satellite imagery.

4. **Probabilistic interpretation**. This strategy normally relies on the relationship between some element of image interpretation and the probable interpretation. Collateral (non-image) information is commonly used in probabilistic interpretation.

5. **Deterministic interpretation**. In this method image characteristics and ground conditions are tied with quantitatively expressed deterministic relationships. A common example is using stereo photogrammetry to determine the height of an object on the photos.

Image Classification for Mid-Level Mapping--It is expected that classification of medium-resolution image data (*e.g.*, Landsat TM) will comprise the basis for mid-level vegetation maps. It is also expected that these classifications will be objective and repeatable methods that result in consistent map products.

Image Classification Tasks:

- Radiometric correction is made for sensor system detectors when the system is not functioning properly. Radiometric correction is also made for atmospheric attenuation caused by scattering and absorption in the atmosphere and topographic attenuation.
- Geometric and terrain correction removes both systematic and systematic geometric errors and makes the geometry of the image planimetric.
- Select image classification logic and algorithm to assign pixels to map units from these four general categories:

1) Unsupervised classification is the identification of natural groups or clusters within multispectral data with subsequent information map unit(s) assignment.

2) Supervised classification is the process of using samples of known identity (*i.e.*, pixels already assigned to information classes) to classify pixels of unknown identity.

3) Unsupervised/supervised hybrid classification is the combination of a supervised and an unsupervised classification.

4) Ancillary data hybrid classification is the use of non-image information with a supervised or unsupervised classification.

- Extract data from training (reference) sites selected from representative and relatively homogeneous land cover classes within the image. Collect spectral statistics for the modeling units representing each training site.
- Select appropriate bands using feature selection criteria to discriminate between classes and eliminate redundant information.

- Extract training statistics from final band selection (if required).
- Extract thematic information and assign modeling units to map units or categories.
- Attribute delineated map features with thematic information.
- Correct for anomalous error in thematic information.
- Error evaluation of classification using the remote-sensing-derived classification map and accuracy assessment (reference) data commonly summarized in an error matrix.

"The overall objective of image classification procedures is to automatically categorize all pixels in an image into land cover classes or themes." "Normally, multi-spectral data are used to perform the classification and, indeed, the spectral pattern present within the data for each pixel is used as the numerical basis for categorization" (Lillesand and Kiefer 2000). There are four general analytical strategies for classifying digital remote sensing data into thematic map units or categories that are likely to be incorporated into the mid-level vegetation mapping process. All of these general analytical approaches are often combined with manual classification of selected classes and/or manual edits of problem areas.

1. The use of an unsupervised classification to identify natural, spectral groups or spectral clusters within multi-spectral data. These clusters of data have unknown thematic content at the time they are created. The thematic labels are later assigned to the spectral statistical groups, often with some grouping or splitting of the original clusters.
2. The use of a supervised classification using samples of known identity (*i.e.*, training data or pixels/regions already assigned to map units or categories) to classify pixels/regions of unknown identity. The training data establish the statistical relationships that comprise the basis for information class assignments to the most probable thematic class.
3. The use of an unsupervised/supervised hybrid classification. This hybrid approach combines the strengths of the two approaches and is very common in vegetation mapping.
4. The use of an ancillary data hybrid classification combining non-image information with a supervised and/or unsupervised classification. This strategy often applies ecological models to constrain the membership in thematic classes, thereby, reducing error. An example of a simple ecological model would be to impose elevation ranges on classes that are not spectrally distinguishable but easily separated based on their biophysical setting.

Reference Data

Reference data collection is a vital part of vegetation mapping projects. Reference data is necessary to successfully complete a mapping project. Emphasis must be placed on designing the reference data collection and identifying training and accuracy assessment sites.

Reference data collection refers to the effort expended to collect quantitative or qualitative data about ground features. Although field data collection is not always necessary, some type of reference data is needed to help interpret and/or assess accuracy during a mapping project. Reference data are frequently collected on the ground through field visits; yet, there are several other techniques for collecting this data. For example, interpreting aerial photographs or observation and taking notes from a helicopter or fixed-wing aircraft have been successful techniques for collecting reference data. Recently, airborne video cameras have been used. Data collection techniques depend on the level of detail needed to satisfy the requirements of the particular mapping project (Congalton and Biging 1992).

In remote sensing projects, reference data serve two main purposes. First, reference data establish a link between variation on the ground and in the image. This link is necessary for assigning image-modeling units (pixels or regions) to discrete land cover classes in the image classification process. Secondly, reference data help assess the accuracy of a map. These two functions of reference data are as follows:

1. Training data are representative areas of land cover that are identified on both the satellite image and in the reference data source. In effect, training data are used to "train" the computer to assign information to a particular modeling unit. For example, a computer classification may separate a lake and a meadow on a satellite image based on spectral differences. The computer, however, won't be able to label lakes and meadows correctly until the appropriate reference information is supplied.

2. Accuracy assessment data, like training data, are samples of land cover and vegetation identified on both the satellite image (classified image) and in the reference data source. While training data are used in the image classification process, accuracy assessment data are used after the classification is completed to assess the accuracy of the final map. The accuracy of a classification is the degree to which the map's identification of various objects on the ground can be corroborated by the accuracy assessment data. For most projects, the same type of data is collected for training and accuracy data.

The most common sources of reference data for remote sensing projects are aerial photo interpretation and field data collection. It is quite common for remote sensing projects to use photo interpretation as a primary source of reference data or to combine these two sources. Numerous references illustrate the development and use of reference data.[8] Many of these studies used photo interpretation in conjunction with field sampling, while many relied exclusively on the photo interpretation to provide these reference data.

Independent of the source of reference data, it is important to promote consistency between the training and accuracy assessment data. It should be of similar type and follow the taxonomic logic and data standards. For most projects, the same type of data is collected for training and accuracy assessment applications.

Thematic Map Accuracy Assessment

Accuracy assessments are essential parts of all remote sensing projects. First, they enable the user to compare different methods and sensors. Secondly, they provide information regarding the reliability and usefulness of remote sensing techniques for a particular

[8] Strahler 1980, Shasby and Carneggie 1986, Cibula and Nyquist 1987, Fung and LeDrew 1987, Chuvieco and Congalton 1988, Leprieur and Durand 1988, Franklin and Peddle 1990, Janssen *et al.* 1990, Marceau *et al.* 1990, Cetin and Levandowski 1991, Loveland *et al.*1991, Peddle and Franklin 1991, Bolstad and Lillesand 1992, Foody *et al.* 1992, Gong and Howarth 1992, Gong *et al.* 1992, Bauer *et al.* 1994, Coppin and Bauer 1994, Green *et al.* 1994, Woodcock *et al.* 1994, Cohen *et al.* 1995, Dikshit and Roy 1996, Shandley *et al.* 1996, Jakubauskas 1997, Johnston *et al.* 1997, Cross et al. 1988, Deppe 1998, and Lo and Watson 1998.

application. Finally, and most importantly, accuracy assessments support the spatial data used in decision-making processes. Too often vegetation and other maps are used without a clear understanding of their reliability. A false sense of security about the accuracy of the map may result in an inappropriate use of the map and important management decisions may be made on data with unknown and/or unreliable accuracy. Although quantitative accuracy assessment can be time-consuming and expensive, it must be an integral part of any vegetation-mapping project.

Quantitative accuracy assessment depends on the collection of reference data. Reference data is known information of high accuracy (theoretically 100% accuracy) about a specific area on the ground (the accuracy assessment site). The assumed-true reference data can be obtained from ground visits, photo interpretations, video interpretations, or some combination of these methods. In a digital map, accuracy assessment sites are generally the same type of modeling unit used to create the map. Accuracy assessment involves the comparison of the categorized data for these sites (*i.e.*, modeling units) to the reference data for the same sites. The error matrix is the standard way of presenting results of an accuracy assessment (Story and Congalton 1986). It is a square array in which accuracy assessment sites are tallied by both their classified category in the image and their actual category according to the reference data (Table 3.22). Typically, the rows in the matrix represent the classified image data, while the columns represent the reference data. The major diagonal, highlighted in the following table, contains those sites where the classified data agree with the reference data.

Table 3.22. Example of an Error Matrix

Reference Data

		Tree Dominated	**Shrub Dominated**	**Herbaceous/Non-vascular Dominated**	**Sparsely Vegetated**	**Row Total**
Classified Data	**Tree Dominated**	**65**	4	22	24	115
	Shrub Dominated	6	**81**	5	8	100
	Herbacious/Non-vascular Dominated	0	11	85	19	115
	Sparsely Vegetated	4	7	3	**90**	104
	Column Total	75	103	115	141	**434**

Overall Accuracy = 321/434 = 74%

Producer's Accuracy User's Accuracy

Tree Dominated = 65/75 = 87% Tree Dominated = 65/115 = 57%

Shrub Dominated = 81/103 = 79% Shrub Dominated = 81/100 = 81%

Herbaceous/Non-vascular Dominated = 85/115 = 74% Herbaceous/Non-vascular Dominated = 85/115 = 74%

Sparsely Vegetated = 90/141 = 64% Sparsely Vegetated = 90/115 = 87%

The nature of errors in the classified map can also be derived from the error matrix. In the matrix, errors (the off-diagonal elements) are shown to be either errors of inclusion (commission errors) or errors of exclusion (omission errors). Commission errors are shown in the off-diagonal matrix cells that form the horizontal row for a particular class. Omission error is represented in the off-diagonal vertical row cells. High errors of omission/commission between two or more classes indicate spectral confusion between these classes.

Useful measures of accuracy are easily derived from the error matrix.

- Overall accuracy, a common measure of accuracy, is computed by dividing the total correct samples (the diagonal elements) by the total number of assessment sites found in the bottom right cell of the matrix.

- Producer's accuracy, which is based on omission error, is the probability of a reference site being correctly classified. It is calculated by dividing the total number of correct accuracy sites for a class (diagonal elements) by the total number of reference sites for that class found in the bottom cell in each column.

- User's accuracy, which is based on commission error, is the probability that a pixel on the map actually represents that category on the ground. User's accuracy is calculated by dividing the number of correct accuracy sites for a category by the total number of accuracy assessment sites, found in the right-hand cell of each row, that were classified in that category (Story and Congalton 1986).

Conducting an accuracy assessment is a multi-step process whose successful completion requires a number of decisions and an awareness of the challenges previously described. Following are the general steps in accuracy assessment:

Step 1: Develop the sampling design.
Step 2: Choose the appropriate reference data.
Step 3: Delineate the accuracy assessment sites.
Step 4: Interpret the assessment sites from the reference data.
Step 5: Compile the classification data.
Step 6: Perform quality control.

Step 7: Build the error matrix.
Step 8: Summarize and present the accuracy assessment results.

Step 1: Develop the Sampling Scheme--There are many opinions about the proper sampling design to use with digital image classification. In most situations, random sampling (simple random or systematic random) without replacement and stratified random sampling will provide satisfactory results (see discussion in Congalton 1991 and Stehman 1992). Random sampling often is not always practical in the field and stratified sampling requires collection of the accuracy assessment sites after the classification has been completed requiring a second field effort. When photo interpretation is the primary reference data source, these limitations no longer apply. Regardless of the specific approach, all sampling schemes should contain an element of randomness to help eliminate interpreter's bias.

The appropriate sample number and size are other important considerations. The number of sample sites must be large enough to be statistically sound, but must be no larger than necessary (for efficiency's sake). More samples will be needed in order to examine the nature of errors in individual categories (the off-diagonal elements in the error matrix), if overall accuracy is to be considered. A general rule of thumb is that at least 20 sites are required for each category in the classification. Congalton (1991) suggests 50 sites for each category and 75 to 100 sites per map unit for large areas with many categories. Evaluating the frequency distribution of class membership by attribute can make an estimate of the appropriate sample size.

The need for statistical validity must be balanced with practical considerations, such as time and budget constraints. Documentation should include discussion of any statistical compromises made. Accuracy assessment sites are expensive and time-consuming to delineate, characterize, and ground check. In determining the number of accuracy assessment sites to investigate, a tactical approach is recommended. Categories of particular importance may warrant more sites; while relatively less important or easily mappable categories, such as snow and open water, may need fewer sites. Additionally, the proportion of field-visited to photo-interpreted sites can be adjusted to balance statistical and practical considerations. For example, many more photo sites may be collected than ground sites, and the ground-visited sites may be selected partly because of their accessibility.

Step 2: Choose the Appropriate Reference Data--Reference data may be an existing map, existing resource inventory data, photo-interpreted accuracy sites, or data collected on the ground. Since a major assumption in quantitative accuracy assessment is that the reference data are 100 percent correct, every effort should be made to secure the highest quality reference data. The analyst should be aware that, in many cases, reliable maps do not exist and inventory data are out-of-date. Often the available data are in a form that is incompatible with the classification scheme. Reference data must conform to the same classification scheme as the classified data to provide anything other than qualitative information.

Care must be taken when using photo interpretations as reference data. Photo-interpreted sites have traditionally been accepted as 100% correct when used to assess the accuracy of digital classifications; however, as Biging and Congalton (1989) observed, perfect accuracy is rarely attributable to photo interpretations. To help minimize errors, the following principles apply: the date of the photos should be close to the date of the digital imagery; experienced interpreters familiar with both the vegetation and the classification scheme must conduct photo interpretations of accuracy sites; and to ensure the accuracy and consistency of the reference data, photo interpretations should be closely inspected.

Using precise ground measurements and/or photo interpretations as reference data is a frequent method of assessing the accuracy of the classified image. In order to minimize costs and maximize efficiency, data from accuracy assessment sites can be collected during the same field visit for collecting training site data. (Note: Accuracy assessment sites cannot be used as training sites. Additional photo-interpreted sites can be collected after the field season, when the photo interpreters have experience with the project area. This combined approach can be a cost-effective means of acquiring accurate reference data.)

Step 3: Delineate the Accuracy Assessment Sites on the Reference Data--Once the sampling scheme, sample size, and reference data are determined, the accuracy sites can be delineated. Since pinpointing the location is critical to determining the accuracy of the classified image, all assessment site locations must be precisely delineated on base maps, orthophotos, resource photographs, or collected with Global Positioning System (GPS). For large projects, developing and maintaining a relational database is an efficient way of organizing and working with accuracy assessment data. Typically, accuracy assessment sites are delineated on resource photographs. Sites should be homogeneous with regard to map category and/or modeling unit (*e.g.*, homogeneous crown closure class, homogeneous species mix, *etc.*). Unambiguous delineation rules must be established. Of utmost importance is that the sampling procedure be unbiased.

Step 4: Interpret the Assessment Sites from the Reference Data--As mentioned in step 2, accuracy assessment data must conform to the same classification scheme as the data used to produce the map. This is true regardless of whether field-verified or photo-interpreted sites are used. The same labeling rules (classification key) used to assign labels to features in the map must be used to label accuracy assessment sites. To eliminate bias, the person collecting the reference data should be very familiar with the classification scheme, but not with the classified map. She or he should have no prior knowledge of the map label for the corresponding accuracy assessment sites.

Step 5: Compile the Classified Data for Accuracy Assessment Sites--Accuracy sites must be precisely located on the classified image or map coverage. Accuracy sites delineated on resource photography can be digitized directly over the satellite imagery or digital orthophotos. Sites with GPS data can be digitally transferred to the GIS . When cross-referencing the vegetation map with the accuracy assessment data, the accuracy assessment site may overlap more that one map feature. When this occurs, determine if the reference site data can be subdivided to follow map feature boundaries. The spatial accuracy of the reference data relative to the spatial accuracy of the map features needs to be considered. If the reference site data cannot be confidently assigned to one or more map features, it should not be used to for map accuracy. The goal is to develop a label for the accuracy assessment site to compare with the map feature label corresponding to the location of the reference site.

Step 6: Perform Quality Control--While quality control is listed here as a separate task, in practice it is an ongoing and iterative process. Errors in accuracy assessments will appear as errors in the classification, thereby resulting in an underestimation of the classification's accuracy. Some common errors include data entry mistakes, incomplete accuracy assessment forms, incorrect location of accuracy sites, incorrect interpretation of the accuracy site, and accuracy sites not entered into the database or missing from analysis.

Step 7: Build the Error Matrix--Tallying each accuracy site according to its accuracy assessment label and classification label creates the error matrix. Many commercial image-processing systems are now providing modules to create and analyze error matrices.

Step 8: Summarize and Present Accuracy Assessment Results--The error matrix and a discussion and analysis of the accuracy results should accompany any use of the classified map to prevent inappropriate uses.

A relatively recent innovation in accuracy assessment is the use of fuzzy sets for accuracy assessments. Traditional accuracy assessment as described in this chapter suffers from certain limitations. First, it assumes that each accuracy site can be unambiguously assigned to a single map category (Gopal and Woodcock 1994); when in truth it may be part of a continuum between map categories. Secondly, the traditional error matrix makes no distinction between magnitudes of error. For example, in a traditional error matrix, misclassifying "conifer forest" as "open water" carries the same weight as the error of misclassifying it as "conifer/hardwood mix."

Fuzzy logic is designed to handle ambiguity and, therefore, should be considered for an accuracy assessment of complex or potentially ambiguous classification. Instead of assessing a site as correct/incorrect as in a traditional assessment, an assessment using fuzzy sets can rate a site as absolutely wrong, understandable but wrong, reasonable or acceptable match, good match, or absolutely right (Gopal and Woodcock 1994). The resulting accuracy assessment can then rate the seriousness of errors as well as absolute correctness/incorrectness. For a complete description of applying fuzzy sets to accuracy assessment, refer to Woodcock and Gopal (1992).

3.3 Field and Aerial Photography Data

In this section:
- ***Identification of sources for data collection standards, protocols, and forms***

The collection and use of field data for map development can be a significant part of the mapping process. For the purposes of this guide, the term “field data” applies to measurements or direct observations made in the field while collecting reference data or making interim map assessments. These field data can exist in a number of formats, but are typically characterized as either plot level data or summary observations of a geographically specific area.

Similarly, the collection and use of aerial photography data for map development can also be a significant part of the mapping process. For the purposes of this guide, the term “aerial photo data” applies to data measured or interpreted from vertical aerial photography following the image interpretation process outlined in section 3.24.

The collection and notation of summary observations for interim map assessment is inherently a more subjective process, relying more on ocular estimation and interpretation than on measurement. This type of field data has limited application, but can be efficiently and cost effectively collected across broad geographic extents and is suitable for collecting training data and reviewing map products during the development stage. No standards currently govern the collection and storage of these data, nor is it the intent of this guide to direct their collection and storage. However, for the purposes of characterizing their utility and ensuring data consistency, a field review approach is outlined in section 3.35.

3.31 Field Data Collection Standards and Methods

Standards for the collection of plot level data for stand exams and vegetation inventories have previously been established (Common Stand Exam (CSE) Users Guide, V1.4.2) and are logically applied to data collection for mapping purposes.

3.32 Field Data Forms

Field data forms are often used to record plot level data for stand exams and vegetation inventory data. These data can also be entered directly into a field data recorder.

3.33 Aerial Photo Data Collection Standards and Methods

A variety of aerial photo interpretation protocols have been used throughout the agency in conjunction with remote sensing projects. Appendix 3B contains an example of an operational photo interpretation protocol applied to remote sensing reference data collection.

3.34 Aerial Photo Data Forms

Aerial photo data forms are often used used to record data from photo interpretation. These data can also be entered directly into an electronic database or spreadsheet.

3.35 Field Reviews

Field reviews conducted for map assessment during the mapping process generally entail summarizing the vegetation composition and structure in a geographically specific manner. Often notation is made about whether the map is accurately characterizing the vegetation or mislabeling it. This information is then used to refine systematic mapping processes (image classifications and ecological modeling rules) and edit map attributes for anomalous error.

Collecting an adequate amount of information requires extensive review of the project area. In large project areas associated with the mid, broad, and national levels, this is usually a rapid assessment process involving vehicle or aircraft travel. Base-level mapping projects may require walk-through observations.

The interim map products are taken into the field as hardcopy maps or as a digital product on a laptop computer. Notes are taken about specific features within the map, noting the composition and structure. Correct map attributes can also be recorded but generally have less utility than basic data that can be categorized into multiple systems. Field review vegetation maps are more easily used when they include road systems, hydrography, and terrain characteristics. U.S. Geological Survey (USGS) 7.5-minute base series maps can serve as an effective overlay on vegetation draft maps to provide this ancillary information.

3.4 Metadata/Documentation

Metadata have been established as a standard part of a final vegetation map product. The FGDC requires that metadata accompany digital map products and, correspondingly, metadata standards for existing vegetation maps are presented in this technical guide. Metadata protocols are taken directly from the FGDC documents detailing the content and format of digital geospatial data.

3.41 Metadata Entry Methods and Verification

In this section:
- ***FGDC metadata requirements for vegetation maps (3.411-3.412)***

3.411 Metadata Required for Existing Vegetation Maps

FGDC Metadata Standards--Metadata or "data about data" describe the content, quality, condition, and other characteristics of data. The Federal Geographic Data Committee approved the Content Standard for Digital Geospatial Metadata (FGDC-STD-001) in June 1998.

Objective--The objectives of the FGDC metadata standards are to provide a common set of terminology and definitions for the documentation of digital geospatial data. Further requirements specific to vegetation classification and mapping are provided in the FGDC approved Vegetation Classification Standard (FGDC-STD-005) in June 1997.

Scope--Executive Order 12906, "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure," was signed on April 11, 1994, by President William Clinton. Section 3, Development of a National Geospatial Data Clearinghouse, paragraph (b) states: "Standardized Documentation of Data, …each agency shall document all new geospatial data it collects or produces, either directly or indirectly, using the standard under development by the FGDC, and make that standardized documentation electronically accessible to the Clearinghouse network."

The standard was developed from the perspective of defining the information required by a prospective user to determine: the availability of a set of geospatial data, the fitness of the set of geospatial data for an intended use, the means of accessing the set of geospatial data, and to successfully transfer the set of geospatial data. As such, the standard establishes the names of data elements and compound elements to be used for these purposes, the definitions of these data elements and compound elements, and information about the values that are to be provided for the data elements. The standard does not specify the means by which this information is organized in a computer system or in a data transfer, nor the means by which this information is transmitted, communicated, or presented to the user. Detailed instructions on developing FGDC Metadata can be found in *Content Standard for Digital Geospatial Metadata*, CSDGM Version 2 - FGDC-STD-001-1998, on the FGDC website.

Refer to appendix 3D for a general interview approach for creating metadata. A standard metadata template is available in appendix 3E.

3.412 Specific Metadata Requirements in the FGDC Vegetation Classification Standard

"Agencies should record and make available the required FGDC metadata during the course of vegetation inventory, whether data has been gathered via remote sensing or fieldwork." This metadata includes but is not limited to:

- Metadata for Field (stand and plot) Samples:
  - Data Collectors: name and affiliation of investigators
  - Date of fieldwork
  - Field Methods: plot design, date of observation/data collection, date of classification
- Geographic Coordinates:
  - UTM or latitude/longitude coordinates of sample
  - The datum (NAD27 or NAD83)
  - Method of determination and estimation of location accuracy information in the form of +/- X meters
- Sampling Design:
  - How, why, and how many sample sites were chosen (subjective, random, stratified, *etc.*)
  - Approximate extent of the stand sampled
  - Where and how the data are stored
- Metadata for Remotely Sensed Samples:
  - Type of imagery (TM, SPOT, aircraft scanner, radar, CIR, B&W, video, *etc.*)
  - Source (mono, stereo, vertical, oblique)
  - Scale or resolution of imagery
  - Date of imagery
  - Methods used to classify type
  - Method of imagery classification (visual or computer assisted)
  - Geographic coordinates (UTM or latitude/longitude coordinates) of samples
    The datum (NAD27 or NAD83);
    Method of determination and estimation of location accuracy information in the form of +/- X m.

3.42 Overview of Database Structure

In this section:

- ***Reference to the corporate database structure for existing vegetation geospatial datasets***

Vegetation map products will be stored and maintained as geospatial databases containing the standard vegetation attributes, regional and local add-on attributes, and internal GIS database fields. Appendix 3F details the location and definition of standard and core-optional data fields required for existing vegetation map product. Valid values tables for the required fields are also included in appendix 3F.

3.43 Data Management

In this section:

- ***Strategy for keeping vegetation maps current and applicable to monitoring***

3.431 Maintaining Existing Vegetation Maps

Baseline Establishment--Key to planning, inventory and monitoring success is the establishment of consistent vegetation baseline information. Once established, changes to vegetation can be determined along with cause of change. This information provides monitoring data to analyze the effects of change in condition of wildlife habitats, late successional old growth, forest health, mortality, growth, and standing forest volumes. Vegetation maps, when combined with ground-based inventories information, are fundamental to meet the needs of Forest and Rangeland Resources Planning Act (RPA), Forest Resource Management Plans, bioregional assessments, and more localized watershed and project planning efforts.

Scheduling Updates--The goal for vegetation resource information is to have vegetation maps no older than 5 years. Update map areas where changes to vegetation have occurred from various causes, such as re-growth, wildfire, harvest, insect and disease damage, vegetation treatments, agriculture or built-out type conversions. Activity databases along with change detection methods are useful in identifying where updates need to occur, as well as determining causes of changes in vegetation cover.

Coordinating Related Work Activities--When programming work in mapping or updating vegetation maps, coordinate with others on a schedule for acquiring resource photography, satellite imagery, and vegetation resource information. Other programs of work, such as surface fuels mapping, ground based inventory, and change detection monitoring programs, can be coordinated with vegetation mapping. Coordinating the acquisition of aerial photos and imagery contributes to the efficiency of all these efforts.

In developing a multi-year coordinated schedule for your Region, consider using physiographic and administrative provinces, National Forest acreages, current status of vegetation mapping, change detection, and Forest Inventory Analysis (FIA) grid inventories, as well as land and resource management plan revision schedules. At the beginning of the cycle for an update area, plan to acquire aerial photography and imagery the summer before any mapping or change detection efforts. Next, schedule vegetation map updates and forest inventory re-measurements of changed areas. And lastly, conduct trend analysis and monitoring by comparing baseline and update information. Yearly budgets need to be stable, if scheduled activities are to stay on cycle. All programs can only realize major cost savings, where current photos and imagery can be substituted for ground-based visits through interpretation. In order to achieve a coordinated cycle, baseline vegetation maps and FIA grid inventory plots need to be completed to a common standard and source dates within a province as much as possible, balancing workloads and budget constraints. By establishing a systematic update cycle for mapping and inventory, opportunities for partnerships outside of the National Forests become more available with state and federal agencies.

Tracking Changes Over Time--To understand vegetation changes on the landscape and its affect on related natural resources, it is necessary to track changes as well as cause of change for comparing to baseline inventories. Tracking imagery source and dates of baseline maps as well as update imagery source and date are necessary metadata. Cause of change is also important to know and aids in analysis of affected resources, such as wildlife habitat and cumulative watershed impacts.